TECHNICAL ARTICLE

Effects of Geotechnical Interest Caused by the Nicoya Peninsula Earthquake, Costa Rica September 5th, 2012

By William Vargas Monge, University of Costa Rica

On September 5th, 8:42 a.m. local time (14:42 GMT), an earthquake of magnitude Mw=7.6 occurred in the subduction zone of the Cocos Plate beneath the Caribbean Plate under the Nicoya Peninsula (shown by an yellow arrow in Fig. 1) of Costa Rica. The epicenter was located at about 160 kilometers west of San Jose, the capital, and at a depth of 18 kilometers, according to LIS, as shown in Fig. 1. Fig. 2 illustrates the distribution of seismic intensity scale. This article briefly reports the findings made during the author's recent site investigation.

An earthquake in the Nicoya Peninsula with a magnitude of 7.5 had been predicted by seismologists of the Observatorio Vulcanologico y Sismologico de Costa Rica (OVSICORI) since the early 1990's (Protti, 1998). The prediction was apparently fulfilled by this event, since it coincided in magnitude and location. However, after the earthquake Protti himself denied it was what he had predicted. Additionally, just days after the event, the seismologists of the OVSICORI issued a public statement announcing that there could be still sufficient stored energy to produce another earthquake of similar magnitude, spurring a scientific public polemic.

The earthquake produced the highest recorded seismic acceleration in the short history of this country, reaching a peak of 1.8 g in the maximum horizontal component at the town of Nosara, near the epicenter (Fig. 3). In spite of the high peak acceleration, important structural damage in the epicentral area all but existed (see Fig. 4 for response spectra), and the earthquake hit mostly non-engineered constructions, sending nearly 1500 people to shelters and leaving some 200 people homeless. Although there were reports of liquefaction in some beaches of the peninsula and along the Pacific coast (Figs. 5, 6, and 7), there was no associated damage since the alluvial deposits occupy a relatively small area and are generally thin.

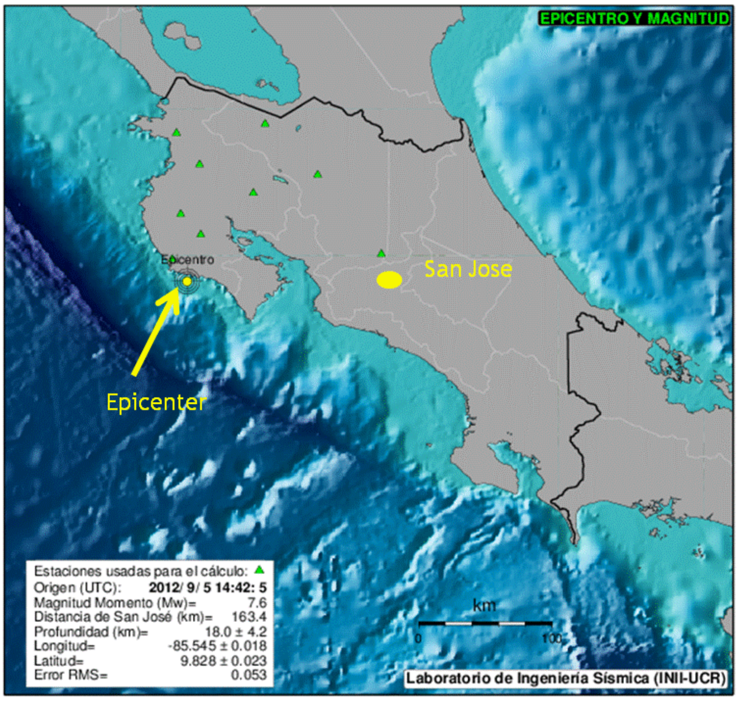

Fig. 1. Location of epicenter. Source: Laboratorio de Ingenieria Sismica, University of Costa Rica.

TECHNICAL ARTICLE (Continued)

Effects of Geotechnical Interest Caused by the Nicoya Peninsula Earthquake, Costa Rica September 5th, 2012

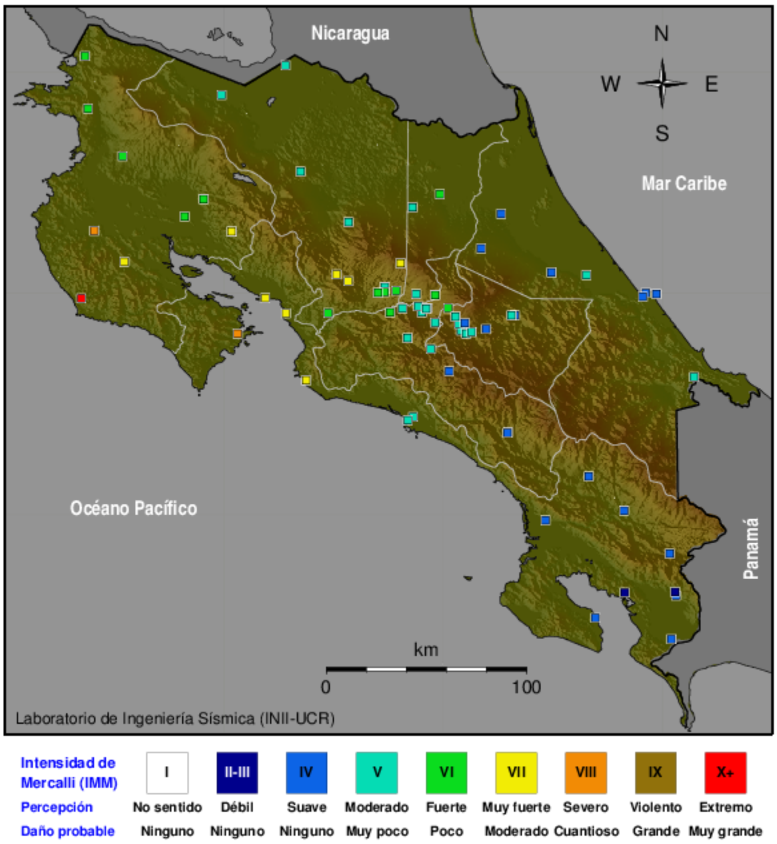

Fig. 2. Distribution of seismic intensity scale; see the highest scale of VIII in the Nicoya Peninsula (Source: Laboratorio de Ingenieria Sismica (LIS), University of Costa Rica)

TECHNICAL ARTICLE (Continued)

Effects of Geotechnical Interest Caused by the Nicoya Peninsula Earthquake, Costa Rica September 5th, 2012

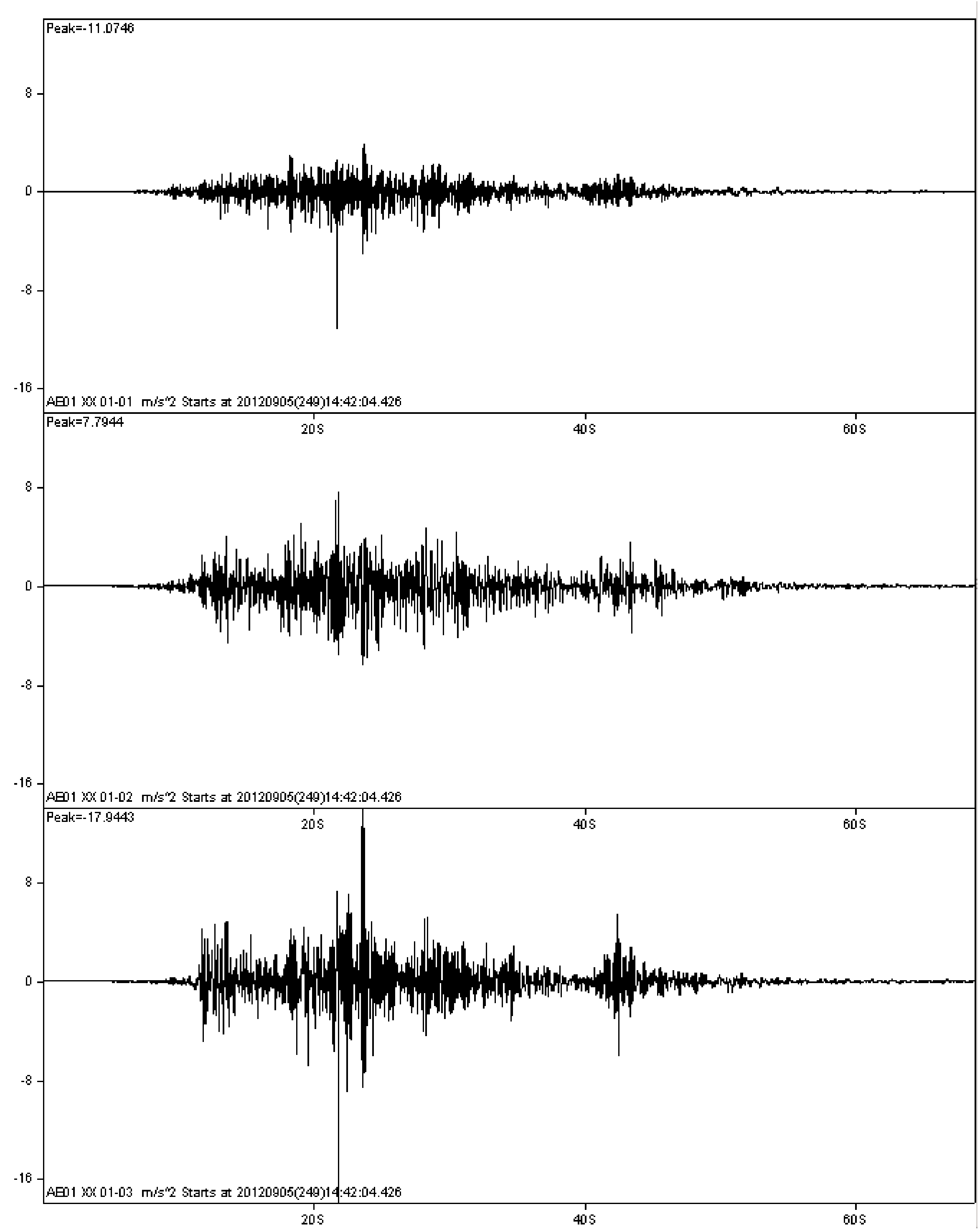

Fig. 3 Acceleration records obtained at Nosara by the Laboratorio de Ingenieria Sismica, Universidad de Costa Rica.

TECHNICAL ARTICLE (Continued)

Effects of Geotechnical Interest Caused by the Nicoya Peninsula Earthquake, Costa Rica September 5th, 2012

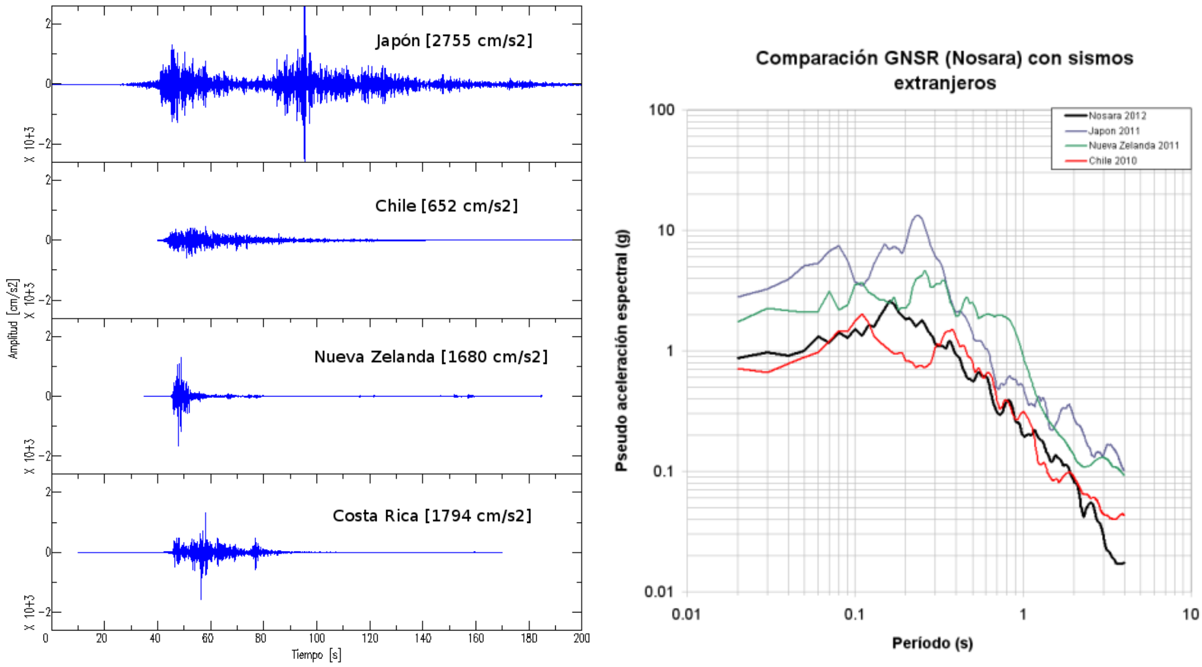

Fig. 4 Comparison of the Costa Rica earthquake and other recent records with high accelerations; Left: time history, Right: response spectra for 5% damping (present earthquake shown by thick black curve).

Fig. 5 Sand boiling in the Caldera beach
Source: Periódico El Imparcial (online version).

Fig.6 Lateral spreading in the Tivives beach
Source: La Nacion (online version).

TECHNICAL ARTICLE (Continued)

Effects of Geotechnical Interest Caused by the Nicoya Peninsula Earthquake, Costa Rica September 5th, 2012

Within the geographic boundaries of the peninsula, the most important infrastructure assets affected by the earthquake were levee for flood control, a cable-stayed bridge and a multi-story RC hospital building. Although the structures were damaged, a technical diagnosis has not been published yet.

The flood-control levee showed longitudinal cracks (Fig. 8) but no significant settlement or instability failures. The preliminary conclusion from the observation is that the damage was not related with liquefaction of the foundation but with tensional stresses induced by the seismic waves at the crest of the levee. It is however possible that the longitudinal cracks were induced by lateral expansion as a consequence of subsoil or levee liquefaction. The Amistad Bridge over the river Tempisque, built in 2002, is the largest of the country and it is a structure composed of a cable-stayed span and a simply-supported span. The two spans seemingly collided and deformed leaving a horizontal permanent shift of 6 centimeters (Fig. 9). The Monsenor Sanabria Hospital (Fig. 10) is the most important facility of this type in the Pacific coast of Costa Rica. It is a reinforced concrete 10-story building with a combination of flexural frames and shear walls. The earthquake caused damage to non-structural partition walls and façade. There was shear cracks in several floor beams of the stairs (Fig. 11) and the building was therefore evacuated.

Fig. 7 Sand boiling through a cracked pavement in Puntarenas.

TECHNICAL ARTICLE (Continued)

Effects of Geotechnical Interest Caused by the Nicoya Peninsula Earthquake, Costa Rica September 5th, 2012

Fig. 8 Tension cracking and slope failure of the Tempisque levee at Filadelfia (Source: La Nacion, online version).

TECHNICAL ARTICLE (Continued)

Effects of Geotechnical Interest Caused by the Nicoya Peninsula Earthquake, Costa Rica September 5th, 2012

Fig. 9 Collision and permanent relative displacement between the two spans of the Amistad bridge (Source: La Nacion, online version).

TECHNICAL ARTICLE (Continued)

Effects of Geotechnical Interest Caused by the Nicoya Peninsula Earthquake, Costa Rica September 5th, 2012

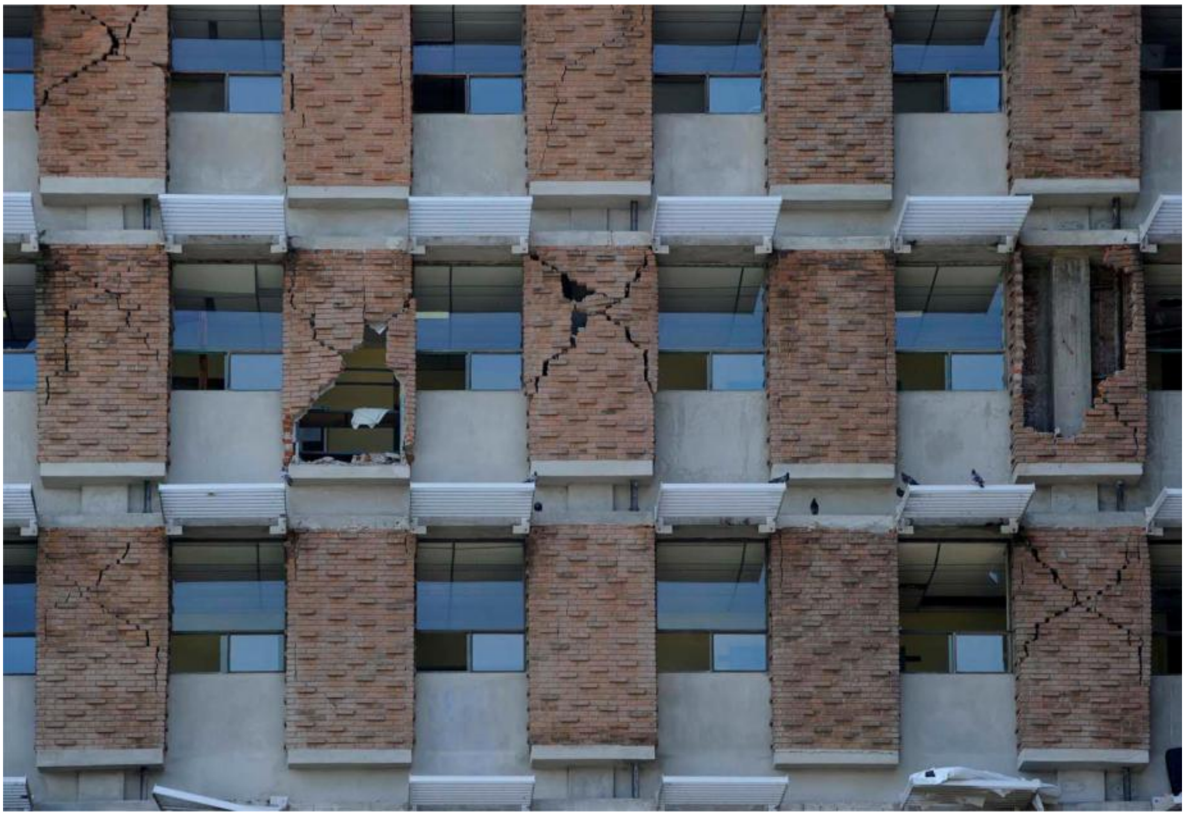

Fig. 10 Shear failure of non structural facade walls of the Monsenor Sanabria Hospital (Source: La Nacion, online version).

TECHNICAL ARTICLE (Continued)

Effects of Geotechnical Interest Caused by the Nicoya Peninsula Earthquake, Costa Rica September 5th, 2012

Fig. 11 Shear cracks in the floor beams of the main stairs of the Hospital Monsenor Sanabria. Source: Laboratorio de Ingenieria Sismica, Universidad de Costa Rica.

According to Laboratorio de Ingenieria Sismica of the Universidad de Costa Rica, the accelerations throughout the country (Figs. 12 and 13) were moderate, considering the magnitude of the earthquake, with the notable exception of the central volcanic mountain range and the Caribbean alluvial plain, where the accelerations were amplified in comparison with those recorded in the central valley, at similar epicentral distances. The acceleration records show that, as the seismic waves traveled away from the epicenter, their frequency content shifted towards the lower range, which contributed to excite the natural frequencies of the foothills constituted by volcanic ashes in the mountain range and the thick alluvium deposits in the Caribbean plain.

TECHNICAL ARTICLE (Continued)

Effects of Geotechnical Interest Caused by the Nicoya Peninsula Earthquake, Costa Rica September 5th, 2012

Amplification was the cause of additional damage at as far as 150 kilometers away from the epicenter. In the central volcanic mountain range, amplification was observed along the ridgelines of the foothills located at intermediate elevations between the valley and the mountain ridge (Figs. 14 and 15). The foothills of the volcanic range have an inverted U shape, created by erosion and the natural drainage and the foothill ridgelines are approximately perpendicular to the main mountain ridgeline, becoming radial around the volcanic peaks at higher elevations. Amplification was seemingly more intense in the ridgelines oriented in a perpendicular direction to the wave propagation trajectory. The combination of the two directions produced large displacements and tensional stresses along the ridgeline, which may be associated with the cracking of the ground and the failure of poorly compacted fills. The combination of these two effects caused damage to several houses observed in the towns of Grecia and Sarchi, at over 125 kilometers from the epicenter (Fig. 16).

In the Caribbean alluvial plain, the most significant damage was the collapse of a railway bridge in the location of Sarapiqui (Fig. 17). The structure is a steel truss bridge which fell off its support by the excessive displacement, which can be associated with the low frequency content of the seismic waves.

Perhaps the most costly damage caused by the earthquake to public infrastructure was the failure of a rock slope in the national route 141, shown in Figure 18, at 120 kilometers from the epicenter. The route is the main transportation way for agricultural products between the Caribbean plain and the center of the country, where San Jose is located. The Ministry of Public Works and Transportation worked for two weeks on removing the massive failure and repairing the damage while the traffic had to take other routes, causing an increment of at least 50 kilometers in the travel distance.

Why so little overall damage?

Although there was damage, it was mostly non structural, not severe and it was located mostly out of the epicentral area. This was somehow a “puzzle” demanding for a scientific explanation. The GPS data of Fig. 19 show that the peninsula moved upwards and towards the West, which means that the Caribbean plate moved over the Cocos plate. Typically, the displacement in subduction zones is such that the oceanic plate moves under the continental plate, projecting the seismic energy toward the continent, but here it was apparently the opposite. The displacement of the upper plate may be associated with most of the released energy being innocuously projected towards the ocean and not towards the continent. Besides that, the (yet to be published) simulations of the rupture mechanism based on the acceleration records in the epicentral area obtained by LIS show that it started in the easternmost boundary and moved towards the West (Moya, 2012, personal communication). This would reinforce the projection of seismic energy in the direction opposite to the country and help in producing little significant damage.

Another important reason for the absence of important structural damage is perhaps that the country has a seismic code which is mandatory by law since 1975. The code has been updated and edited twice and its most recent version is from 2010. Since the beginning of the code in the academic realm, it helped in creating a seismic-resistant construction culture which has permeated to the workers, who became proficient in building with reinforced concrete and masonry. In this aspect, Costa Rican is closer to other Latin American countries with high anti-seismic design and construction standards, such as Chile.

Conclusions:

The Nicoya Peninsula earthquake of September 5, 2012 was an event which did not live up to the expectancy of a large magnitude earthquake. Although there was damage associated it was not what can be typically seen for earthquakes of similar magnitudes in populated areas. In spite of large accelerations, in the epicentral area the damage was non-structural and the geotechnical effects such as soil liquefaction did not produce associated damage to important infrastructure.

TECHNICAL ARTICLE (Continued)

Effects of Geotechnical Interest Caused by the Nicoya Peninsula Earthquake, Costa Rica September 5th, 2012

The most interesting effect from the geotechnical viewpoint was the amplification that was observed in the foothills of the central volcanic mountain range and in the Caribbean plains, over a hundred kilometers from the epicenter. The amplification can be associated with long periods which occur in soft soils (volcanic ash and alluvial deposits) as well as in some topographic features. This local effects manifest with great intensity for the first time and will have to be considered in the next edition of the Costa Rica Seismic Code.

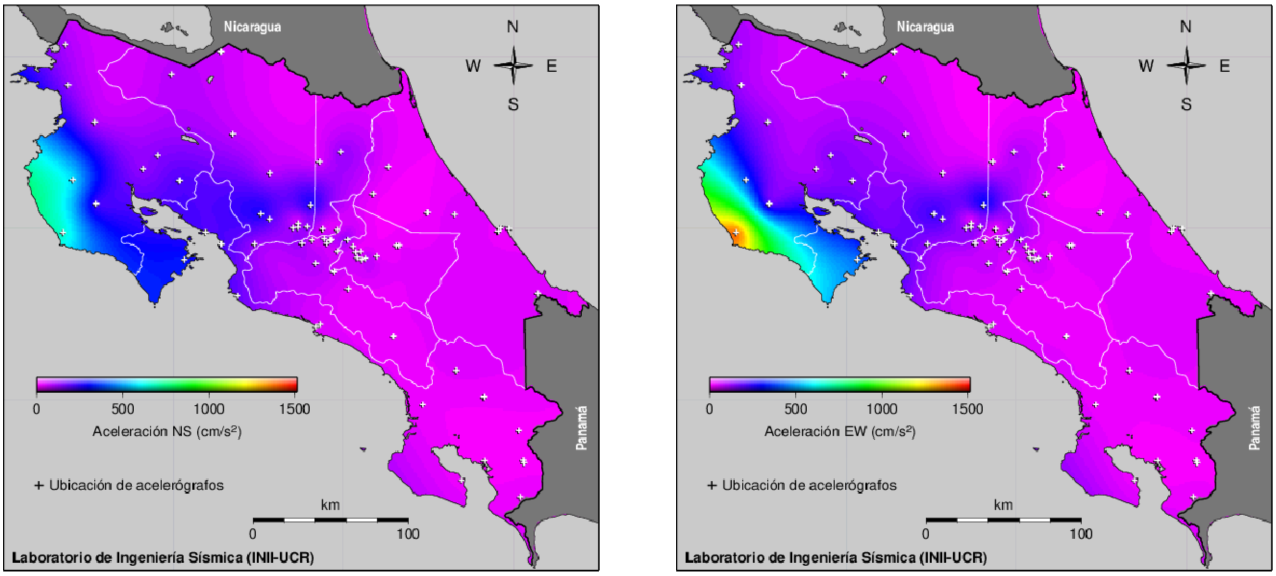

Fig. 12 Maps of interpolated horizontal accelerations by Laboratorio de Ingenieria Sismica, UCR. Left: North-South components. Right: East-West components.

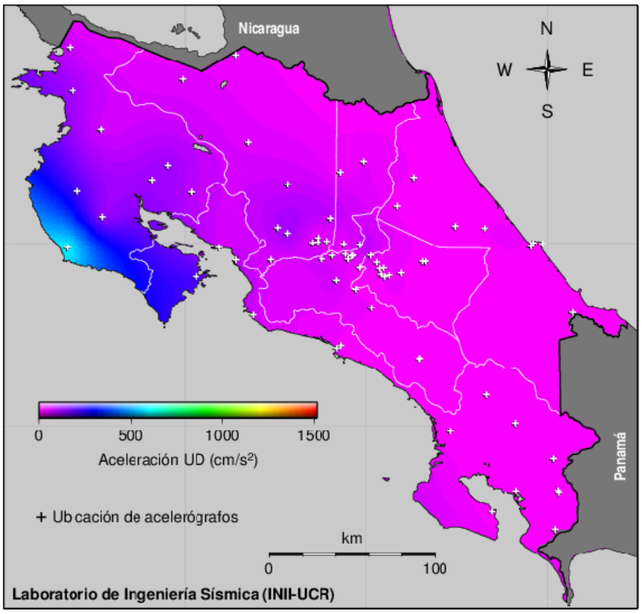

Fig. 13 Map of interpolated vertical accelerations by Laboratorio de Ingenieria Sismica, University of Costa Rica; Left: North-South components, and Right: East-West components.

TECHNICAL ARTICLE (Continued)

Effects of Geotechnical Interest Caused by the Nicoya Peninsula Earthquake, Costa Rica September 5th, 2012

Fig. 14 Foothills of the mountain range in Sarchi (Photograph by W. Vargas).

Fig. 15 Failure of unstable fill in Sarch (Photograph by W. Vargas).

Fig. 16 Tension cracks and failure of a fill in La Fortuna (Source: La Nacion, online version).

Fig. 17 Collapse of a railway bridge over river Sarapiqui at Puerto Viejo (Source: La Nacion, online version).

TECHNICAL ARTICLE (Continued)

Effects of Geotechnical Interest Caused by the Nicoya Peninsula Earthquake, Costa Rica September 5th, 2012

Fig. 18 Failure of a rock slope on route 141 (Source: La Nacion, online version).

TECHNICAL ARTICLE (Continued)

Effects of Geotechnical Interest Caused by the Nicoya Peninsula Earthquake, Costa Rica September 5th, 2012

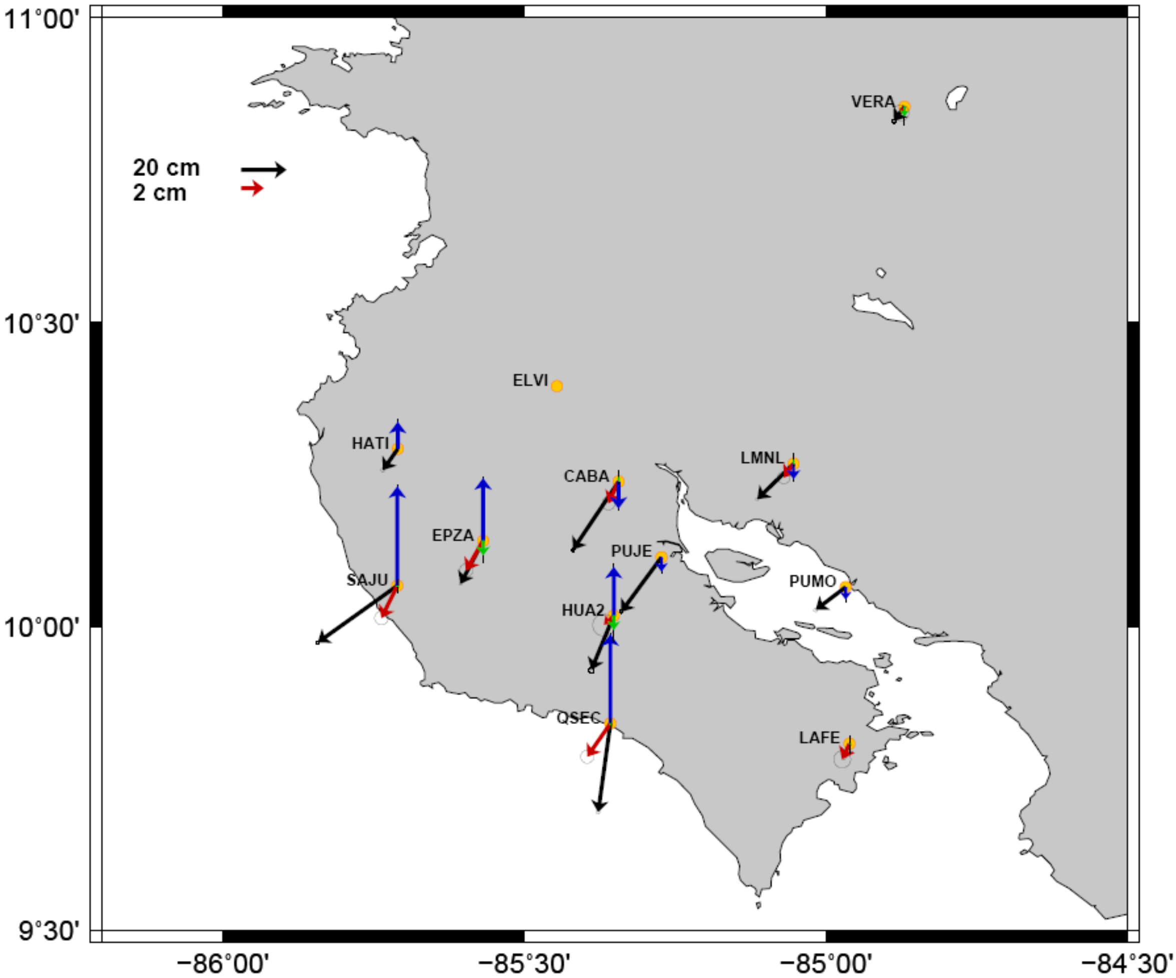

Fig. 19 Coseismic and postseismic displacements of the Nicoya peninsula associated with the September 5 event. Black vectors show coseismic horizontal displacements and blue vectors represent coseismic vertical displacements. Red (horizontal) and green (vertical) represent postseismic offsets up to Sept 10, 2012 (Source: Dixon, 2012).

Printed references:

Protti, M. (1998) “Alerta temprana a San José por un terremoto debajo de la Peninsula de Nicoya” Volumen de Ponencias de la Reunion hemisferica de la Decada Internacional para la Reduccion de Desastres Naturales, San Jose, Costa Rica. Comision Nacional de Emergencias.

Online references

http://www.lis.ucr.ac.cr/: Site of the Laboratorio de Ingenieria Sismica. All acceleration data (time histories, spectra, maps) can be downloaded without cost.

http://www.nacion.com/: Main webpage of the Costa Rican newspaper “La Nacion”.

http://wp.me/p10fH0-ys/: Site of the Costa Rican online bulletin “El Imparcial”.

Dixon, Tim. September 5, 2012 M 7.6 Costa Rica Earthquake: Geodetic Data Available for Research. ftp://sideshow.jpl.nasa.gov/pub/JPL_GPS_Timeseries/20120905_CostaRica/