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The April 22, 1991 Limón (Costa Rica) earthquake

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ABSTRACT: The 1992 main Limón earthquake had Ms 7.6, strong-motion duration (at San Isidro) 26.6 s and maximum MM intensity XI. With epicenter near the Caribbean coast, the shapes of its isoseismals differ markedly from the code-specified isoacceleration curves for various return periods, as the latter curves assume that all seismic sources are close to the Pacific coast. On the other hand, code design spectra are overconservative for long periods, especially on soft ground. These matters demand a code revision.

Although the death toll was moderate, there was considerable material damage especially in the province of Limón, including widespread liquefaction and ground failure, which damaged roads and railways. Main causes for damage to buildings were, as is often the case, insufficient transverse reinforcement, poor detailing, short columns prone to brittle failure in shear, and soft first story. Storage-tank and bridge failures are also analyzed. The danger of a macroseism within densely populated areas is brought out.

1 INTRODUCTION

The main shock had a magnitude Ms 7.6. It occurred at 15:57 local time with epicenter 43 km SE of Port Limón at a 10 km depth. Fig 1 shows estimated MM intensities. The earthquake caused the failure of buildings, bridges and infrastructure in general and severe damage to roads and industrial facilities. The number of fatalities was less than 100. About 4000 dwellings were destroyed and 12 000 more suffered partial collapse, mainly associated with poor construction. Some 250 small schools were damaged. In Limón the water supply system developed many ruptures and required several weeks for repair. This paper deals with seismicity, design practice in the country and direct material losses caused by the earthquake.

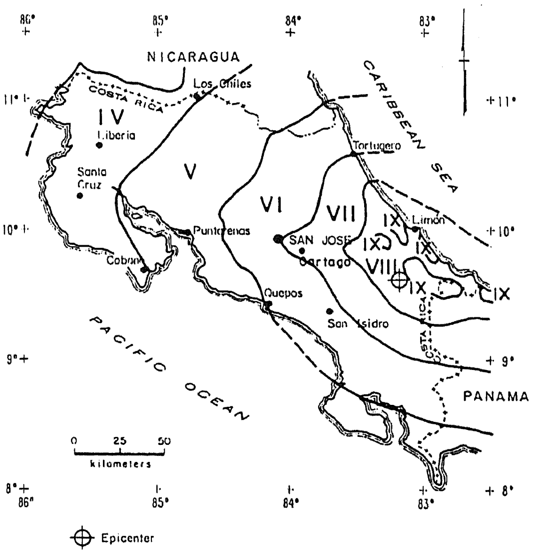

Fig 1. MM intensities of the 1991 main shock (after Rojas, 1991).

2 SEISMICITY AND DESIGN IN COSTA RICA

The 1986 Seismic Code (Código Sísmico de Costa Rica) uses isoacceleration maps, based on Mortgat et al (1977), for return periods of 50, 100 (fig 2a), 500 and 1000 (fig 2b) yr. The latter reflects the assumption of three source zones, all near the Pacific coast. Santana (1990) gives examples of damage from a recent earthquake with epicenter in Nicoya Gulf off the Pacific coast. Yet the April 22, 1991 event occurred near the Caribbean coast, far from the assumed source zones.

Significant events with magnitude greater than 7.0 have occurred along the Caribbean coast from Nicaragua to Panama (Miyamura, 1982). They include the destructive earthquake of 1916 (Ms=7.4) causing much damage in Bocas del Toro and felt strongly in Limón, and the 1953 event (Ms=5.5) near Limón. That the zoning maps ignore sources near the Caribbean coast is due to imprecision in locat-

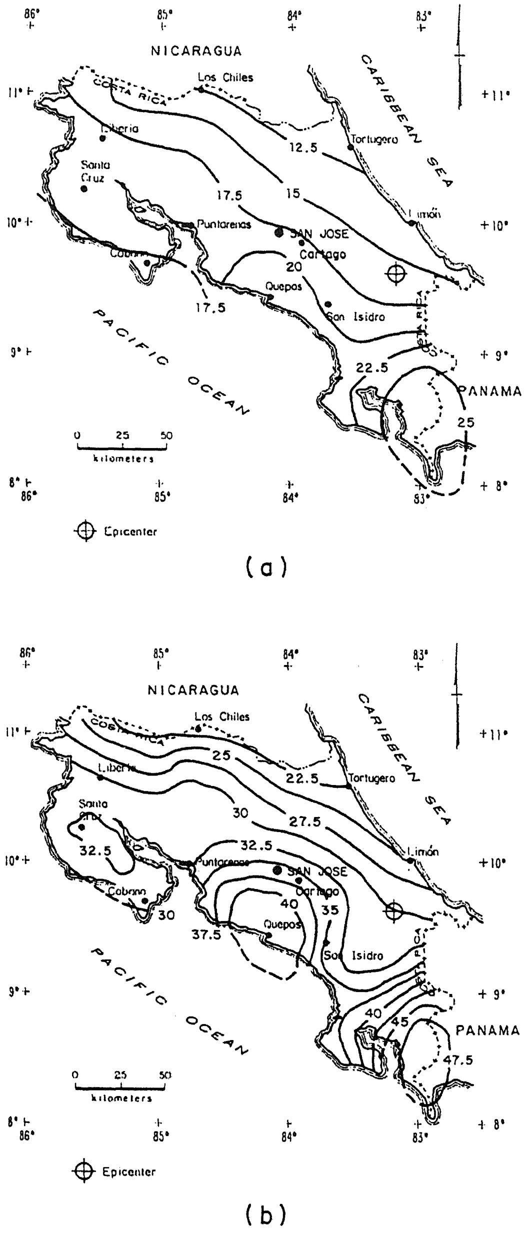

Fig 2. Code issoacceleration curves for a) 100 yr return period; b) 1000 yr return period.

ing the foci because of lack of a seismological network.

Rather than using an importance factor the code allows the designer to choose the structure's life and corresponding exceedance probability. This determines the return period. An ordinary structure with 50-yr design life and 40% exceedance probability has a 100-yr return period. The designer interpolates linearly between contours in fig 2a. The code provides response spectra for rock, hard soil and soft soil, and specifies ductility factors of between 1 and 6. (See Santana, 1988 on the code, and Sauter, 1989 on seismicity.)

The code requires modal analysis for structures taller than 30 m and allows static analysis for lower structures. In both methods the peak acceleration is obtained from the isoacceleration maps. For 1-2 story buildings a simpler approach is permitted; the country is divided into three zones (fig 3); base shear coefficients are 0.11, 0.22 and 0.33 for zones I, II and III, respectively.

3 INTENSITY OF DAMAGE

The maximum MM intensity was IX in Matina, just north of Highway 32, along Highway 36 on the coast south of Limón and in Panama next to Costa Rica (fig 1).

Electric power in Limón was interrupted for about 24 hr. No major damage was reported on the main transmission lines. Local distribution lines experienced many cable breakages.

Severe ground fissures forced the closing of Highways 32 and 36, nine bridges suffered severe damage or collapse and significant settlements occurred in bridge approaches where intensities reached VIII and IX.

Coast uplift of 1.5-2.0 m was observed. This exposed a coral reef in Limón which had been below sea level.

Ground failure and liquefaction were reported throughout most of the 12 000-km^2 epicentral region, in the province of Limón. The area is dominated by a broad plain sloping gently from the Talamanca Mountain Range to the Caribbean. The plain is dissected by several large and many small river valleys that broaden as they approach the coast. Most liquefaction occurred in alluvial and fluvial deposits under the river floodplains; also in lagoonal and estuarine deposits under coastal lowlands. About 30% of the highway pavement was disrupted by cracks, scarps and settlements caused by liquefaction (EERI, 1991), and several railways segments were misaligned. The greatest ground-induced damage took place at river crossings, where bridge decks were thrust over abutments, piers shifted riverward and fills settled as much as 2 m (Youd et al, 1992).

4 STRONG MOTION DATA

Accelerograms were recovered from 14 of the 19 permanent stations deployed by the Earthquake Engineering Laboratory of the University of Costa Rica (Santana, 1991). Ten of the 14 instruments were on free field or from low-rise structures; the rest on high-rise buildings. The closest strong-motion station, in San Isidro, on hard ground 73 km from the epicenter (fig 1) registered maximum accelerations of 0.20g horizontal and 0.17g vertical (Santana et al, 1991). The maximum free field acceleration recorded was 0.27g, in Cartago, on soft ground 94 km from the epicenter. The Costa Rican Electricity Institute and the Seismological and Vulcanological Observatory maintain a number of additional instruments.

At San Isidro the strong shaking (5-95% of the Arias intensity) lasted 26.2 s, much longer than at Presidio during the 1989 Loma Prieta earthquake and in the 1986 San Salvador earthquake. Comparison of the 5%-damping response spectrum for the strongest San Isidro component with the code design spectrum and with that derived from the Newmark-Riddel criteria (fig 4) shows that the latter spectrum is in reasonable accord with the response spectrum but that the code overestimates spectral ordinates for long periods. This is more pronounced for the Cartago station, on soft ground (fig 5). As a consequence structures with long fundamental period, designed according to the code, are overdesigned, especially on soft ground. The situation is brought out in fig 6, which shows ductility demands for single-degree-of-freedom systems designed for a ductility factor of 4. Qualitatively the same holds for other design ductility factors. (The apparently excessive demand in very rigid structures is doubtless covered by their overstrength. — Note by the editor.) This helps explain the low-damage incidence to large buildings in San José's metropolitan area.

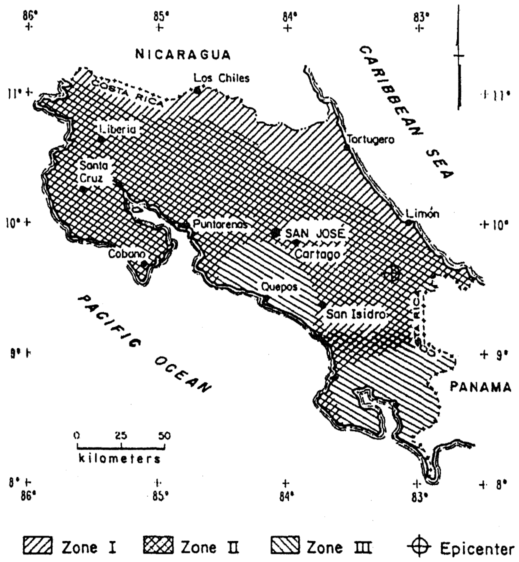

Fig 3. Code seismic zones for simplified design.

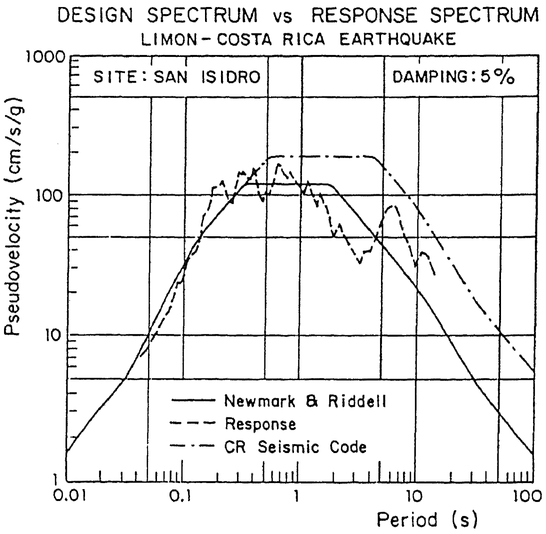

Fig 4. Response and design spectra, San Isidro Station.

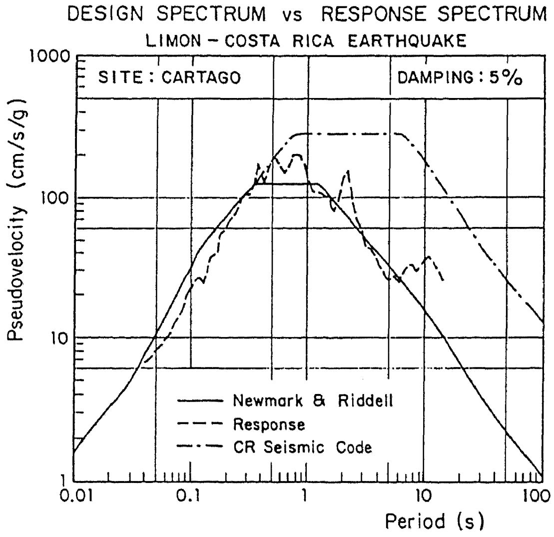

Fig 5. Response and design spectra, Cartago Station.

5 DAMAGE TO HOSPITAL IN LIMON

The important Dr Tony Facio Castro Hospital built in 1982 was evidently not designed to resist strong earthquakes. A large four-story wing suffered severe damage. Its reinforced concrete frame had end masonry filler walls above the first story. This resulted in a soft story and the ensuing shear distress in the first-story columns. The end walls forming the stairwell were connected to each floor slab through one 20-mm bar which pulled out. The lightweight precast fiberreinforced panels having styrofoam cores failed in shear and fell through the ground-floor corridor roof. There was also much nonstructural damage caused by large story drifts and by rain infiltration. This wing had to be closed. The remaining lower rise wings remained operational.

6 DAMAGE TO HOTELS IN LIMON

The four-story Las Olas Hotel, built on reinforced concrete piers founded on the coral bed that experienced significant uplift during the earthquake underwent partial collapse and serious damage. The structure had columns of various lengths. One of the shorter columns failed in shear. The 400 by 600 mm column was reinforced with four 30 mm longitudinal bars and 12 mm ties at 300 mm. Its clear height was only 950 mm. The longitudinal bars were spliced in the critical region and the ties were much corroded. Another first-story column suffered severe shear distress owing to the presence of a spandrel beam which resulted in a short column.

This hotel had a major discontinuity in its shearwall which ends abruptly at the ground floor. The corresponding columns underwent brittle shear failure, which prevented the rest of the structure from developing its lateral load capacity.

The three-story International Hotel failed in the first story and collapsed. The 300 by 600 mm first story columns had embedded plastic pipes and were reinforced with eight 25 mm longitudinal bars and 9.5 mm ties at 300 mm, ending in 90° bends which became ineffective after concrete-cover spalling. This particular deficiency has been observed in many other earthquakes. The beam-column joints had no transverse reinforcement and were poorly detailed, so the hooked bars from the beams pulled out of the joints.

The two-story Ng Hotel experienced shear failures in its poorly detailed short columns and in the shearwalls. The partially infilled walls between columns reduced the latter's clear height, a feature that has caused damage in other earthquakes (Newmark and Rosenblueth, 1971; Mitchell et al, 1986; Mitchell, Tinawi and Redwood, 1990).

7 DAMAGE TO INDUSTRIAL FACILITIES

Limón port facilities suffered severe ground damage due to liquefaction of the sand fill. A one-story light structural steel-frame warehouse had permanent lateral deformations in the columns. One section of a steel wharf with timber decking collapsed; its steel members were so badly corroded that only a fraction of their sections remained. Lighting poles 12 m tall founded on large footings underwent permanent rotation of foundations resulting in a 7° tilt.

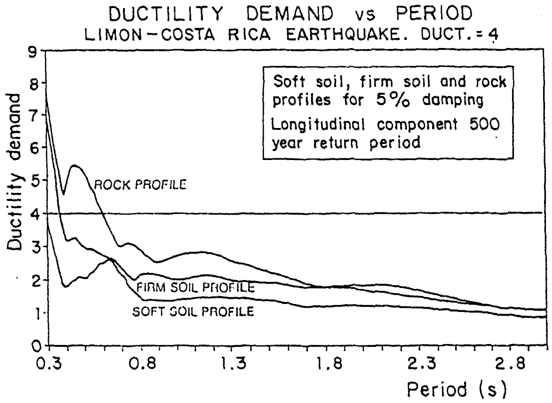

Fig 6. Ductility demands in a single-degree system designed for ductility factor of 4 according to the code.

The Instituto Costarricense de Electricidad (ICE) generating plant in Moín was built in 1977. Its capacity is 32 MW. Although there was evidence of severe ground movement and liquefaction, the equipment was undamaged except for minor oil leaks and the need for tightening the anchor bolts of a diesel engine due to settlement of its foundation.

The main building housing the generators is a 10 m tall one-story light steel structure. Its lateral load resisting system consisted of tension-only bracing in some bents. A number of these 75x75x5 mm angle braces buckled evidencing the poor performance of this type of structural solution.

Three adjacent cylindrical oil tanks suffered damage at their supports. These 80-m^3 tanks had a diameter of about 3 m and overall length of 10.6 m. They were supported on five legs. Two different details were used for the supports. One of the legs typical for two of the tanks suffered weld tearing at the junction with the tank as well as permanent deformations. These supports were not anchored to the strip footing. The end supports bent severely and the leg caused buckling of the tank wall. Performance of the tanks having different support details was much better. The legs were braced and anchored to longitudinal and transverse support beams, the longitudinal ones in turn anchored to a strip footing. Although the tension-only braces buckled there was no permanent movement nor damage to the tank walls. The damage to the braces is easily repairable.

A warehouse with reinforced concrete frames that was under construction and is part of the ICE facility suffered serious damage due mostly to its short columns brought about by masonry filler walls. These columns failed in shear at their tops and developed flexural hinges at the bottom of their unsupported lengths. The joints failed in shear due to lack of transverse reinforcement; beam reinforcement, bent down at 90°, pulled out.

The RECOPE oil refinery in Moín suffered important damage in the plant facilities and oil storage tanks. Structural damage to the process equipment was light. Two fires broke out.

Many tanks in the refinery had been filled the day preceding the earthquake. Fifteen of them, ranging in capacity between 560 and 117 644 barrels, failed in various ways. One containing naphtha and diesel oil exploded landing 50 m away. Others suffered sloshing, top wall buckling, elephant-foot buckling and float-roof tilting, and a spherical LNG tank that was under construction collapsed.

8 DAMAGE TO BRIDGES

Nine bridges in the epicentral region were badly damaged or collapsed. Following the earthquake, road access was impossible to Limón on Highway 32 and to areas south of Limón on Highway 36. Minor damage was reported in bridges crossing Rivers Toro, Rojo, Escondido, Aguas Claras, San Miguel and Banano.

The crossing of River Viscaya on Highway 36 is a two lane bridge with three 22-m simple spans, located about 10 km south of Limón. It was designed in 1971. The abutments have vertical and battered piles and the concrete piers rest on piles embedded over the height of the piers. The soil consists of fine sand. Due to very large ground movements one pier collapsed causing loss of support of two spans. A horizontal restraining device held the superstructure together over the other pier. Bridge ends were subjected to large rotations and a tension failure developed in one abutment.

The bridge over Bananito River has two simple spans 25 and 28 m long on skewed supports. The deck collapsed owing to abutment slumping and rotation.

In the village of Bomba, a few kilometers from the Bananito River bridge, a simple-span steel-truss railway bridge crossing the Banano River was very badly damaged owing to failure of the abutment foundations caused by large-scale ground displacements. The bridge had to be closed to traffic.

In the eight-span bridge crossing the Chirripó River on Highway 32 about 30 km west of Limón, the six interior spans have haunched continuous girders while the two shorter spans are simply supported. The west-end span collapsed due to loss of support over the first pier, resulting in closure of the bridge for one week. There was no restraining device over this pier. The structure was temporarily repaired by lifting the collapsed span and placing it on its original support over the pier, and the bridge was reopened to traffic. Work was underway to enlarge the pier foundation to accommodate four steel columns providing additional support for the girders. This collapse emphasizes the need for restraining devices between adjacent simple spans.

The continuous spans were undamaged despite a 100 mm transverse displacement of the superstructure on one of the piers. Supports of these spans consist of a rocker bearing having transverse sliding capability. Transverse displacement is somewhat restrained by keeper plates welded to the top of the slider and bolted to the rocker assembly below the sliding joint. Keeper plates failed due to the significant transverse displacements.

9 CONCLUSIONS

The Limón earthquake caused a considerable disruption in all aspects of life for the affected region. The local infrastructure suffered extensive damage. The impact had to be borne by all levels of society as well as by the government. The cost of repairing or replacing all the civil works and housing damaged was higher than estimated and far above the capabilities of public offices. The fast recuperation must be partly credited to national and international relief organizations.

However, the impact of the earthquake was concentrated in a small area, about 12 000 km^2, that is sparsely populated and mostly dedicated to agriculture. Had the epicenter been located in the Central Valley, where two thirds of the country's population lives, the effects would have been much greater. One of the most important lessons of this earthquake is that a new shear zone cutting across the middle of the country and splitting the Central Valley in two has been identified. The significance of this finding is enormous and can now be properly documented with an adequate reinterpretation of the historic evidence.

Data recovered from this earthquake will doubtless contribute to the further understanding of the Central American earthquakes. The strong motion records have already helped interpret the behavior of the building inventory in different parts of the city of San José and have shed some light in the parameters currently used in the region for the estimation of attenuation laws.

Finally, the limited impact of the earthquake and the rapid recovery should not be taken as indicative of low vulnerability. A false sense of security would help increase the unassessed vulnerability to seismic hazard in Costa Rica and in Central America.

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