

## EARTHQUAKE DAMAGE, AND MITIGATION MEASURES

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### INTRODUCTION:

The most severely stricken area by the violent shaking caused by the earthquake in Limón covers a surface of approximately eight thousand square kilometers (8,000 km<sup>2</sup>), most of which lies in Costa Rican territory (nearly 80%), and the rest in Bocas del Toro Province, Panama. This area is limited by an intensity (Modified Mercalli) (Rojas, 1991), greater than VII but less than VIII (VII < MM < VIII), where the damage or effects on the land or environment as well as to man and his works have been significant or evident, for which this region receives the name of damages area (fig. 1, caption). Approximately two hundred thousand (200,000) people live there, (MIDEPLAN and others, 1990). The damaged or stricken area (fig. 1) can be geomorphologically divided into three zones:

a. The alluvial plain, narrow and parallel to the Caribbean coast, with the Estrella and Baja Talamanca-Sixola valleys, limited towards the inside by the piedmont of the last counterforts of the Talamanca Cordillera, with general altitudes of less than a hundred meters over sea-level (100 msnm), and which reaches levels near to 200 m. only towards its southeastern extremity. The average annual temperature ranges from twenty-five to thirty degrees Centigrade (25 °C), an average annual rainfall between three thousand and three thousand five hundred millimeters (3000 ≤ P ≤ 3500 mm), and very high humidity levels

throughout the year (Chinchilla, 1987).

The agricultural (mainly banana), commercial and port activities converge in this coastal zone, as well as the development of population and civil and industrial infrastructure, being Limón the largest and most important city within the affected area, where nearly sixty thousand people live in its surroundings, while the remaining zone has a less dense population. This zone also has the greatest seismic vulnerability, something fully illustrated by the severe material destruction caused by the earthquake, although the number of people who died (23), is completely out of proportion in relation to the damage and intensity of the violent quake (VIII  $\leq$  IMM  $\leq$  X) Denyer (1991).

b. Mountain zone, which extends from the border with the plain (100 or 200 m.), until reaching the continental divide of waters (fig. 1), with maximum heights of 3820 mts. and rainfall higher than 3500 mm. This zone corresponds with the Caribbean slope of the Talamanca Cordillera, characterized by severe-slope declivities, where numerous landslides produced by seismic shaking were generated in its mid-inferior level. These slides affected the virgin forests of the biospheric reserve, "La Amistad," as well as the hydrographical basins of the region's most important rivers, coinciding with the earthquake's mesoseismic area.

The density of population is extremely low, and it basically corresponds to small indigenous groups which subsist under isolated and precarious conditions, and which were also affected

by the violent seismic shake.

c. Intermountainous Turrialba valley and surroundings, located between 500 and 1000 mts, possesses a hot and humid climate in the low parts, which improves in the high parts with an average annual rainfall of more than 3000 mm. (fig. 1).

This is the country's internal zone that, after Limón, suffered the most significant effects, with 59,389 inhabitants concentrated in the city of Turrialba, who are dedicated to agricultural activities, basically coffee and sugar cane growing, complemented with small dairies. The greatest damage was reported in houses and the ground, such as landslides. The intensity (MM) of the seismic shaking in this zone was greater than VII but less than VIII, and only material damage was produced.

In the following sections, the aspects related to the most significant damage and direct losses caused by the earthquake will be focused in a selective and complementary way, as well as the most relevant mitigation measures put into practice.

## **DAMAGE AND LOSSES**

The most noticeable damage and losses are found in the "life-lines" such as roads, railroads, bridges and port facilities, as well as aqueducts. The damage resulting on the telephone and electric distribution network and on Limon's airport was of less consideration. The Limón-San José oil pipe line responded satisfactorily, while damage on the storage tanks and the fire in the refinery (RECOPE) were severe. (Morales,1991)

The damage on the vital lines seriously affected the population and the agricultural sector, obstructing an adequate attention of the emergency and the rehabilitation of those zones affected by the earthquake, particularly the alluvial plain, where the banana activity and the people who settle there and depend on the said crop are concentrated. Banana has become one of the first export products of the country; besides, the port system of Limón-Moin is Costa Rica's main one, so much for exports (85%) as for imports (60%) of goods and merchandise. The only alternative left to face the emergency during the first days was airway; but for the southern part of the city of Limón, it was a period of weeks to months, due to the breaking down of four important bridges and the destruction of the road, including the railway. The other sector that was most affected was the housing sector, mainly in 1 or 2-story constructions, while only a few buildings suffered severe damage: a three-story building collapsed (one person died), an also three-story building (Las Olas Hotel) partially collapsed, and Limón's hospital building (Tony Facio Hospital) underwent significant destruction, mainly non-structural, and the hospital's patients and personnel were evacuated, which made the emergency attention activities more difficult, having to transfer hospital patients as well as the earthquake's severely injured victims to San José, by means of air transportation.

a. Lifelines

- Roads: The greatest damage occurred on the only national route (# 32) which communicates the city of Siquirres with Limón, and

in route # 36, Limón-Sixaola, in the limit with Panama (Fig. 1). These roads have been constructed to a great extent upon artificial in-fills, which in turn are constructed upon a natural in-fill, which is the alluvial plain, usually with water-saturated soils, and which will respond poorly in the presence of seismic loading generated by seismic shaking, whether by liquefaction, differential settlement or subsiding, which are responsible for the road's collapse or for the lateral displacements that develop severe ruptures of the road bed, including the in-fill. It was spectacular to observe how cracks extended for kilometers along the road's axle and on other occasions, the road was cut transversely by cracks that reached a depth of more than 2.0 mts.

The national route Siquirres-Limón, of asphalt pavement surface, suffered from severe to total damage lengthwise of 25 kms, between the Barbilla and Blanco rivers (Fig. 1), while the national route Limón-Sixaola, also made of asphalt pavement, suffered from severe to total damage along 60 kms, of which almost 50% resulted in total destruction, most of all in the approaching spans near the rivers' pass, where there were more in-fills.

Adjacent roads made of asphalt pavement, concrete or gravel, that communicate the principal route with nearby towns also suffered severe damage and it was necessary to rebuild a total of 24 kms; meanwhile, the canton's road network rehabilitation, approximately 200 kms of gravel roads, called for another great effort.

To sum up, it is necessary to rebuild or rehabilitate nearly 309 kms, at an approximate cost of 1, 015.8 million colones (U.S.

\$8.7 million).

- Bridges: The land's nature, the strong shaking and the structure's own characteristics all united to cause a spectacular and severe impact on some bridges, which left the region isolated.

On the national road Siquirres-Limón, six bridges placed over Rojo, Toro, Cuba, Blanco and Chirripó rivers were badly damaged. The most important and significant damage was to the bridge over Chirripó river, because the northwestern approaching span (16 mts) collapsed, cutting the passage of the only road to Limón. Within four days, the passage over the bridge of Chirripó river was rehabilitated, using a provisional in-fill. This is the longest bridge in Costa Rica (430.7 mts).

On the national route Limón-Sixaoña, the bridges over Vizcaya, Bananito, Estero Negro and Estrella rivers also collapsed in a spectacular way, and damage was less significant on the Banano and Sixaoña bridges. During the first months, provisional bridges were placed to provide the passage by this road which leads to the tourist sector of southern Limón, it communicates small towns and it is the only way out for the zone's producers. At the present, the passage over Estrella river is suspended after waters rose in April 92 and leveled the provisional platform.

The total losses due to the bridges of national roads that collapsed or were damaged amount to 725 million colones - (U.S.\$6.21 million).

- Railroads: These extend through the alluvial plain to the northwest as well as to the southeast of Limón (Fig. 1). For more than 75 years, it remained the sole means of communication with the rest of the country, and the only means for the transport of passengers, goods and merchandise. Nowadays, it is mainly used to transport banana from different plantations to Limón's port - Moín. The most affected branches are those of Siquirres-Limón, where 51 kms suffered diverse damage, and Limón - Valle de la Estrella, with 41 kms.

Most frequently, the damages are the rupture or twisting of rails, displacement of crossties and the railway, in many cases caused by settlement or lateral displacement of the land or the in-fill, where there was a significant liquefaction of the soil, as happened with the roads.

Eight other bridges were also damaged, four of which were significantly damaged but did not collapse, two on the Siquirres-Limón branch, mainly the channel bridge and over the Matina river, while on the southern branch of Limón, the bridge over Bananito river partially collapsed and in Valle de la Estrella, the Atalanta bridge. The soil liquefaction phenomena together with connected deformations plus the seismic shaking, contributed to the destruction observed on these bridges, though their metallic structure reacted better.

The damage generated on the railroad infrastructure, including facilities as repair shops, machinery and special equipment raise losses to an amount of 1,152.3 million colones (U.S.\$9.87 million).

- Ports: Port infrastructure was affected not only by the violent seismic shaking, but also by the elevation of the coastal shelf which reduced the waters' depth in nearly 1.5 mts. It was necessary to dredge the coralline rock, in both Limón and Moín in order to recover its draught.

Even though the docks did not stop operating, their capacity was notably reduced (30%). Port infrastructure damage, such as storerooms, repair shops, loading and unloading yards, alignment of cranes, pilots and access routes need an investment of - including improvements and dredging - approximately 1,778.0 million colones (U.S.\$15.2 million).

- Aqueducts: One of the most severe problems faced by Limon's population and by those responsible of attending the emergency and rehabilitating the drinking water services was the damage on the harnessing, piping, storage and distribution systems of drinking water.

There are three supplying sources (500 liters/second) for the city of Limón and its surroundings (Fig. 1), Río Blanco, Moín, and the main one is La Bomba (70%), where there is an intake of water of Banano river and a treatment plant, besides a well battery. Two aqueducts go from La Bomba to the city of Limón, the most recent one has a length of 15 kms and a diameter of 500 mm, with an external and an internal concrete coating, which takes 2.5 months to repair (Picado, 1991). The oldest and narrowest one (300 mm), made of fused iron is 17 kms long, and it follows the railroad route, while the new one approximately follows the old road. Both suffered multiple ruptures in their

routes, 120 damages on the new concrete one, and 50 damages on the old iron one (the aqueduct from Moín to Limón, 12 kms long and a diameter of 300 mm, made of ductile iron, suffered 25 damages and was the first to be repaired). In the distribution network there were about 470 damages, specially in the asbestos-cement pipe-lines, leaving the city with a three-month water rationing (Picado, 1991). Other smaller systems which were also affected were the rural microaqueducts (23) used by smaller towns, which aggravated the earthquake's destructive effect.

The losses in the harnessing, treatment, piping, storage and distribution systems of drinking water and the sewerage systems require - including improvements - an investment of 2,772.0 million colones (U.S.\$23.7 million).

Other vital lines, such as the "telephone and electrical network" suffered less damage, compared to that discussed in the preceding lines and pages, and this service was reestablished by sectors in terms of one to seven days in faraway zones. Its losses are included in the Energy sector in Table 1, where a summary of direct losses per sector is shown, according to the data of the Regulating Plan (National Emergency Commission, 1991), to internal documents of the Commission (Rosales, 1991), and in general, to the updated files of the National Emergency Commission, starting from direct government sources.

b. Housing: The number of houses that existed in the affected area, based upon data offered by Chinchilla (1987), MIDEPLAN and others (1990), is estimated in nearly 44,000 houses. According to data of the Special Housing Commission (Comisión Especial de

Vivienda - CEV - 1992), a total of 12,321 were partially or totally damaged, which means that more than 25% of the houses were damaged; consequently, near 50,000 people experienced problems with their houses, of which 4,452 were declared as totally damaged or destroyed, and estimating five members per family, that gives a total approximate of 22,260 people with urgent housing necessities.

The greatest amount of houses that were damaged or destroyed is found in the "alluvial plain" zone, where most are constructed over wood piles which generally form a first floor or a space between floors, over which the wooden house, properly said, is set up or constructed. In this way, people protect themselves from the ground's dampness and frequent floods. The soil's alluvial nature responds inadequately to seismic shaking, whether due to amplification processes or to differential settlement, and that along with the house's characteristics, will make it go through deformations that damage the house.

The total amount of the losses, taking into account CEV's data (1992), with 4452 houses destroyed, 4679 severely damaged and 3190 moderately damaged, sums up to an estimate of 5,193.0 million colones (U.S.\$44.46 million).

c. Agricultural sector: The principal activity is carried out in the banana plantations which extend throughout the alluvial plain, which consists of bland, fertile and deep soils saturated with water, where the use of channel networks for draining is necessary. The violent earthquake generated both soil and drainage destruction, liquefaction phenomena, settlements and

ground rupture, which combined with direct crop damages plus damages on the plantations' infrastructure, such as roads, internal transport systems, plant and storerooms, seriously impacted the production. On the other hand, the interruption of lifelines for transports (roads and railroads), and the limitation of port activities, also contributed to an increase of losses in relation to the country's and the region's main export product.

The small owners of traditional crops for subsistence or for local consumption, or for export purposes, such as cacao, suffered a proportionally larger impact, because their operative capacity and resources are limited. Besides, the incommunication problems subsist due to the interruption of roads and railroads; particularly, for southeastern Limón, and mainly for the southeastern sector of La Estrella river where the bridge collapsed and was still unrepaired in April, 1992. Furthermore, the spates that occurred in April, 1992, destroyed the provisional passage. The sector's losses, including banana production, the banana that was not exported, the non-traditional production and the subsistence production is nearly 7,102.3 million colones (U.S.\$60.81 million).

The totality of direct losses by sectors, including all sectors that suffered significant damage, are shown in Table 1, where the total amount sums up to 21,991.9 million colones (U.S.\$188.3 million), always using the rate of exchange to the earthquake's day (1 dollar = 116.8 colones) (April 22, 1991). Comparing the total amount of direct losses to the country's gross domestic

The Energy sector includes losses in the refinery (1,080 million colones) and in the telephone and electrical system. The Health sector shows losses suffered by hospital infrastructure, including hospitals, clinics, health centers and rural health offices.

In the Social sector are indicated: direct expenses used for humanitarian attention, medical care, food, acquisition, storage and distribution of drinking water, shelters, victuals, transport, fuel, support personnel and others.

Included in the Education sector are losses due to damage on the infrastructure and didactic materials of primary and secondary schools and damage suffered by four buildings on University of Costa Rica's campus.

Losses due to damage on other public, private, industrial or commercial buildings have not been considered, whether from Limón or from other parts of the country, which means that the totality of direct losses may surpass the amount of U.S.\$200 million.

#### **MITIGATION OR COUNTERMEASURES**

The objective during the emergency phase (first weeks), concentrated at first on "humanitarian aid," and later on the "infrastructure's rehabilitation." In order to accomplish these two objectives, it became necessary to establish and maintain:

- a. An airlift (San José - Limón - isolated communities), with a Regional Emergency Operations Center, installed at the Airport of Limón.
- b. A radio communications network.

- c. Level of coordination with national or local state institutions, friendly nations and communal or non-governmental organizations, with logistic activation and support to local emergency committees;
- d. Urgent medical attention brigade;
- e. Public health brigade;
- f. Supply and distribution brigade;
- g. Evaluation of damages brigade;
- h. Shelters brigade;
- i. Scientific or technical groups.

The corresponding state institutions were in charge of the rehabilitation tasks, with the help of communal, non-governmental organizations and of friendly nations (Morales, 1991).

A "Regulating Plan" was established for the reconstruction tasks, and the Government of Costa Rica is responsible for its execution and is supervised by the National Emergency Commission (1991).

This document presents a diagnosis of the damages and a specific action plan for each of the affected sectors and the guidelines for its execution. The fundamental sectors are the following:

Aqueducts and sewerage system (ICAY--Instituto Costarricense de Acueductos y Alcantarillados), energy (MIRENEM--Ministerio de Energía y Minas - RECOPE--Refinería Costarricense de Petróleo), electricity and telecommunications (ICE--Instituto Costarricense de Electricidad), agriculture (MAG--Ministerio de Agricultura y Ganadería - Private Sector), public works and transports (MOPT--Ministerio de Obras Públicas y Transportes - INCOFER--Instituto Costarricense de Ferrocarriles - JAPDEVA--Junta de Administración

TABLE 1  
 ECONOMIC LOSS  
 BY SECTORS

SECTOR	QUANTITY IN MILLIONS	
	LOCAL CURRENCY	%
LIFELINES	7,453.6	33.89%
AGRICULTURE	7,102.3	32.29%
HOUSING	5,193.0	23.61%
ENERGY	1,244.4	5.66%
HEALTH	340.8	1.55%
SOCIAL	337.8	1.54%
EDUCATION	320.0	1.46%
TOTAL LOSS in millions		
Colones	21,991.9	100 %
TOTAL LOSS in millions		
Dollars (USA)	188.3	100 %

network (University of Costa Rica).

f. Regulations of Foundations: The Soil Mechanics and Foundation Engineering Association has wanted to take advantage of the earthquakes' teachings (1990-91) where the site's effect has been relevant for the different degrees of destruction observed. The objective is to obtain regulations that can guide and establish criteria or general and particular rules according to the type of soil or land that will be used for constructing.

g. Atlas of Natural Hazards and Vulnerability: The Prevention and Mitigation Direction of the National Emergency Commission, with the contribution of the University of Costa Rica and the Information System of the Housing Sector, along with an exchange of data and information with different public and private institutions, has been developing an "information system" with a relational data base, alphanumeric and graphic, which will allow to establish a national territory zoning, and a more rational use of soil in accordance with the different levels of hazards and vulnerability, and which will conduct the mitigation or preparation activities of the population or the response in the presence of emergencies.

h. National Emergency Plan: The National Emergency Commission together with state institutions and non-governmental entities is elaborating a plan which will allow to determine the hierarchical, functional and operative structure of authorities and organisms, along with a coordinated management of entities and resources for the development of programs and activities in the "before, during and afterwards" phases of disasters.

#### FIGURE CAPTIONS:

In the square compartment, the most affected area by the earthquake and its relation to the rest of the country and neighboring countries is shown. The epicenter and causative fault are included, as well as the capital city's location within this context.

The amplified figure presents the affected region's physiographical characteristics, with a coastal "alluvial plain", separated by the elevation of 100 to 200 mts (continuous thick line) of the mountainous zone. The development of civil and population infrastructure in the "alluvial plain" should be observed (see symbology). The vigilance stations of hydrographical basins are also indicated (with a small filled rectangle). The water supply sources can be observed near the port city of Limón (small unfilled triangles).

#### TABLE CAPTIONS:

Presents direct losses for the different government sectors, without including private enterprise, industry or commerce (except banana production and export). The author has obtained the data from Rosales (1991) and from the revision and updating of the files of Prevention and Mitigation Direction of the National Emergency Commission.

Virgin forest destruction (65 square kilometers) along with its flora and fauna due to the slides, as well as aquatic life in the coral reefs due to the elevation of the coastal shelf are irreparable or invaluable, the same as 23 killed people, the same as 23 killed people.

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#### ACKNOWLEDGEMENTS:

I wish to give my most expressive thanks to many persons and institutions that with their effort and dedication have made it possible to know about the causes and effects of Limón's earthquake, in complement to the attention, rehabilitation and reconstruction of the affected region. The information collected by the National Emergency Commission and that is found in its files, comes from many diverse and varied sources, some of which are written personal communications, others are bulletins or internal reports, and a few are slightly formal publications. All of these have contributed to this publication in a smaller or larger degree.