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Provisional Report on the January 13, 2001 Earthquake Occurred Off The Coast of El Salvador

(updated 15, February, 2001)

PREFACE

El Salvador, one of the smallest and most crowded nations in Central America, extends about 240 kilometers westward from the Gulf of Fonseca to the border with Guatemala. This country was struck by two devastating earthquakes within a month. The first quake of Jan. 13, 2001, which was centered off El Salvador's southern coast, damaged and/or destroyed nearly 280,000 houses, and killed at least 844 people, including hundreds of residents buried in a huge amount of soil slipped down Las Colinas mountainside in the city of Neuva San Salvador (Santa Tecla). While authorities were trying to gauge the scope of the tragedy, the second quake of magnitude 6.6 hit several central provinces on Tuesday, Feb. 13. The second quake, killing at least 322 people and destroying more than 34,500 homes, was also substantially big in terms of damage

It was Jan. 19, Japan Society of Civil Engineers (JSCE) had an executive meeting, and it was officially decided that JSCE would dispatch an investigation team to El Salvador. Though JSCE covers a quite vast area of interest, the reconnaissance team, which was a small party of 8 professionals (**Table 0.1**), had little chance to cover up every specialty of civil engineering during their short stay (Feb. 1-6) in El Salvador. The preliminary strategy of JSCE team was thus to make a first reconnaissance laying stress on the landslide-inflicted damage to dwellings as well as the damage to civil infrastructures, and to discuss with Salvadorian specialists about possible future collaborations lucrative for both El Salvadoran and Japanese sides.

On February 1, the team was fully briefed on the entire scope of the earthquake-related damage by Mr. Jose Antonio Rodrigez, General Manager, Geothermal of El Salvador. Mr. Rodrigez, together with Mr. Salvador Handel, Geothermal of El Salvador, kindly made every arrangement for the team's reconnaissance trip, coordinating the schedules of specialists and officials in charge in such authorities as the Ministry of Environment, Ministry of Public Works, Ministry of Housing and other organizations including PRIMSA, CIG, UCA and etc.

With necessary pieces of information provided, JSCE team members could investigate efficiently the areas affected by the first earthquake of Jan. 13. The areas included (a) Las Colinus, Los Choros (Landslide group), (b) Rio Lempa, San Agustin, Berlin and Santiago de Maria (Strong-Ground-Motion and Civil-infrastructure groups) (**Table 0.2**). The landslide group surveyed 3D configurations of landslides (scars, slid soil masses and etc) using a laser rangefinder with a digital compass built in. They also took soil samples for ring-shear tests. The Strong-Ground-Motion and Civil-infrastructure groups measured microtremors to evaluate local site conditions and to find predominant periods of a variety of structures.

Mr. Saburo YUZAWA, Ambassador, Japanese Embassy in El Salvador, kindly took all the trouble of negotiating with ministers concerned over every possible convenience that the Salvadorian counterparts could provide, and the El Salvador military gave the team members a lift in a helicopter, allowing a wide coverage of extensive areas affected by the earthquake. Mr. Yuzawa also took the trouble of coordinating an assembly of Salvadorian specialists and officials in charge for discussing with the JSCE team members the findings that the JSCE team members obtained through their reconnaissance. The assembly was held at Radisson Hotel, San Salvador, on Feb.6.

This provisional report outlines the findings obtained through the reconnaissance and some individual comments, which are not yet the conclusions reached after a thorough discussions among the members. The final report should be released after we obtain the results from microtremor analyses, geotechnical tests on the soil samples and etc. However, providing quickly both Japan and Salvadorian specialists and persons in charge with a rough-an-ready overview would be important for taking measures for the disaster relief and precautions against possible secondary disasters. All the members of the JSCE Reconnaissance Team would like to express hereby their sincere sympathy to those people affected by the two devastating earthquakes, and they wish to further collaborate with Salvadorian specialists for possible countermeasures, e.g., reconstruction of damaged structures, retrofitting of existing structures and reducing landslide hazards.

Table 0.1 List of members of the JSCE Reconnaissance Team

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Table 0.2 Schedule for reconnaissance trip

<table>
<tr><th></th><th>Leader</th><th>Landslide</th><th>Strong ground motion</th><th>Civil infrastructures, Lifelines, Adobe & masonry structures</th></tr>
<tr><td rowspan="2">Feb. 2</td><td colspan="4">Briefing at Geothermal, San Salvador
Jose Antonio Rodrigez, Director General
Salvador Handel
Javier Rivas
Jose Antonio Rivas</td></tr>
<tr><td>Japan Embassy
Saburo Yuzawa, Ambassador
Tetsuo Iwasaki</td><td>Ministry of Environment
Ernesto Lopez Zepada</td><td colspan="2">Ministry of Environment
Carlos Pullinger</td></tr>
<tr><td>Feb. 3</td><td>Survey: Las Colinas
Refugee camp
Mario Jvarez
Local government, Neuva San Salvador</td><td>Helicopter</td><td colspan="2">Survey: Las Colinas</td></tr>
<tr><td>Feb. 4</td><td>Survey: San Vicente
Berlin (Geo-thermal)
Santiago de Maria
San Agustin
Railway bridge, Rio Lempa</td><td>Survey: Las Colinas
Los Choros</td><td colspan="2">Survey: (Strong ground motion, micro tremors, civil infrastructures, adobe houses) RC bridge at Rio Lempa, San Agustin, Berlin, Geo-thermal, Santiago de Maria</td></tr>
<tr><td rowspan="3">Feb. 5</td><td>Meeting at JICA
Atsushi Kamisawa
Takahiro Shinchi
Takayoshi Jose Yamagiwa</td><td rowspan="2">Mr. Daniel Hernandez
CIG
Survey: Las Colinas</td><td rowspan="2">UCA</td><td>Carlos Duque, Vice ministry of Public Works,</td></tr>
<tr><td>Ministry of Housing
Martha Eugenia Roldan</td><td>Ministry of Housing
Martha Eugenia Roldan</td></tr>
<tr><td colspan="4">Dinner with French Mission
Dr. Richard Guillande</td></tr>
<tr><td rowspan="2">Feb. 6</td><td>PRISMA
Herman Rosa, Director
Jose Roberto Duarte Saldana</td><td>CIG
Survey: Las Colinas</td><td></td><td></td></tr>
<tr><td colspan="4">Meeting at Ilopango, Radisson
Ana Maria Majano, Minister of Environment
Scott Baxter (Seismologist)
Ernesto Lopez Zepeda
Rina de Jarquin
Ministry of Public Works
Carlos Duque, Vice minister
Rene Gomez, executive director
JICA
Atsushi Kamisawa, Director, Tsukamoto, Takayoshi Jose Yamagiwa, Shinchi
Japan Embassy
Saburo Yuzawa, Ambassador
Tetsuo Iwasaki</td></tr>
</table>

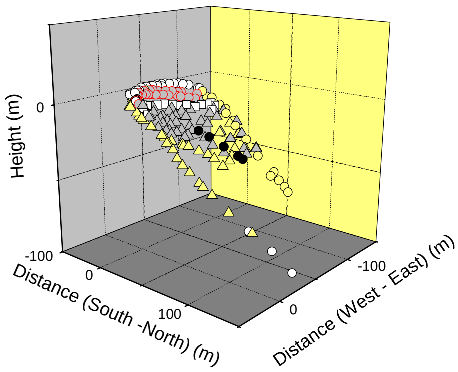
1. LANDSLIDS

1.1 LAS COLINAS LANDSLIDE

(1) Geological and Geotechnical Features of Slide

A large amount of soil mass (about 75,000 m^3) was thrown off the rim of a mountain ridge rising south behind Las Colinas area of Neuva San Salvador (Santa Tecla). The elevation of the head-scarp and the toe of the slide are 1076m and 935m, respectively, namely, there is an average gradient of 141 m over 440 m distance in the exposed failure surface. The failure surface can be roughly divided into two zones (**Fig. 1.1(a)**). The uppermost zone (zone 1) is a hollow of about 100m in diameter, which was caved in some 20-30 m from the original ground surface. South beyond the hollow, there appears a steepest slope (zone 2) of about 51° gradient, which becomes gradually gentle as it comes close to the toe. One of the most noticeable and important aspects of this landslide was its long travel distance through the city. The distal end of the slid soil mass reached 450m further south of the toe.

Using a laser rangefinder with a digital compass built in, the 3D configuration of the upper hollow (zone 1, **Fig. 1.1(a)** and **(b)**) was first surveyed from two reference points, one on the left edge of scar (closed circle in **Fig. 1.2**: N13 396.87’, W89 17.168’) and the other on the right (not plotted in Fig. 1.2). The distances from the top end of the scar to the toe of the slope and to the farthest reach of the soil mass are 480m and 750m respectively. A possible soil mass that was fitted in the upper hollow is roughly estimated to be about 75,000 m^3, and is presumably the greater part of the soil, which flushed more than 600 lives to death.



Right: Exposed failure surface and flattened dwellings by slid soil mass

Above: 3D configuration of the upper hollow, Las Colinas Landslide

Fig. 1.1 Las Colinas landslide: The exposed failure surface comprises two zones; the upper hollow and lower steep slope.

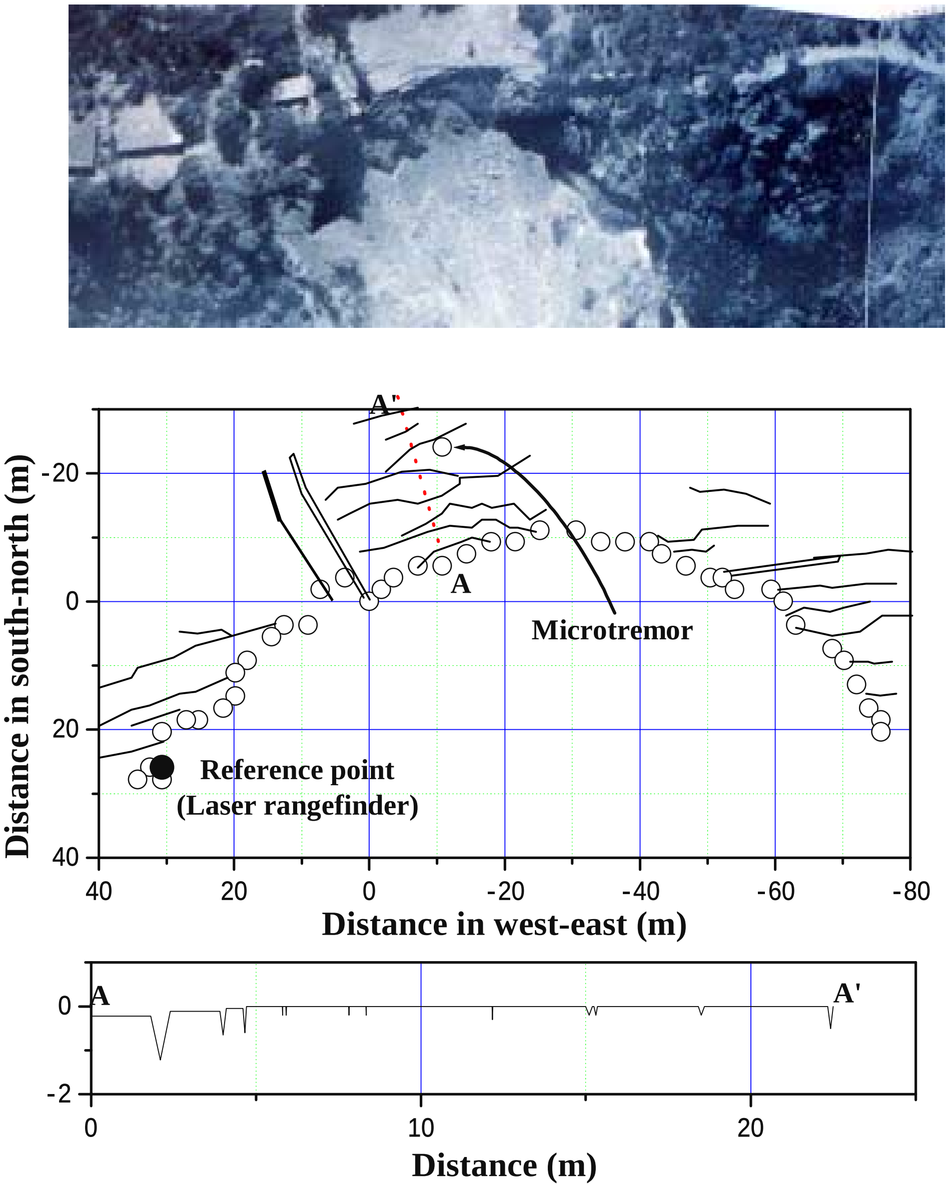


Fig. 1.2. Perimeter of scar, Las Colinas Landslide

Table 1.1 Crack openings along Line A-A7

No.	Distance from A (cm)	Vertical offset (cm)	Opening (cm)	Cumulative opening (cm)	Depth (cm)
1	180-240	10	60	60	122
2	390-410	7	20	80	65
3	460-471	5	11	91	60
4	580-581	0	1	92	20
5	590-593	0	3	95	20
6	780-782	0	2	97	20
7	833-834	0	1	98	20
8	1215-1217	0	2	100	30
9	500-1502	0	2	102	20
10	1525-1535	0	10	112	20
11	1841-1859	0	8	120	50
12	2234-2249	0	5	125	20

Total 43 points were marked along the perimeter of the scar using a GPS receiver (**Fig. 1.2**). Behind the scar, there were extensive cracks running in almost west-east. Crack openings (12 visible cracks; **Table 1.1** and **Fig. 1.2** (below)) were measured along Line A-A'. Total 1.25 m's opening was reached over the 22 m's distance of Line A-A'. Namely, about 5% average strain was induced within the soil behind the scar. Extensive cracks were found along the ridge crest even in areas that did not slide (**Fig. 1.3**); the cracks are certainly the threat of further slides.

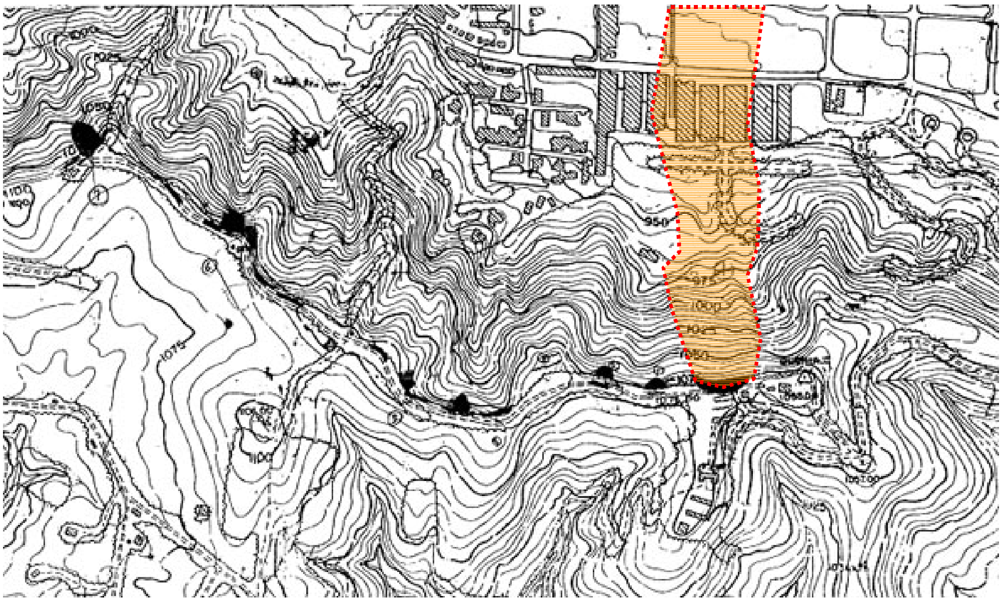
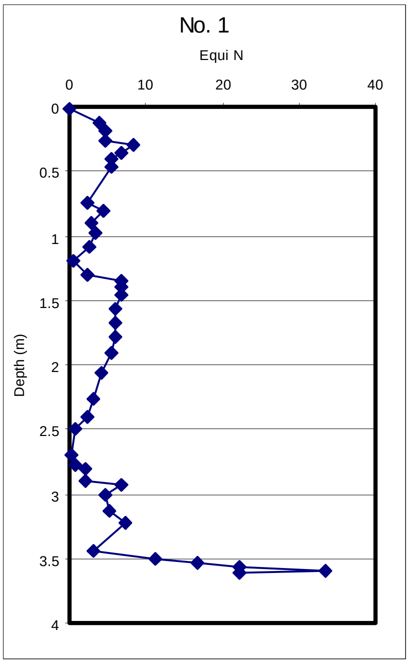


Fig. 1.3. Crack map



(a) Above: Location of sounding

(b) Right: Equivalent N values

Fig. 1.4 Sounding using cone-penetrometer

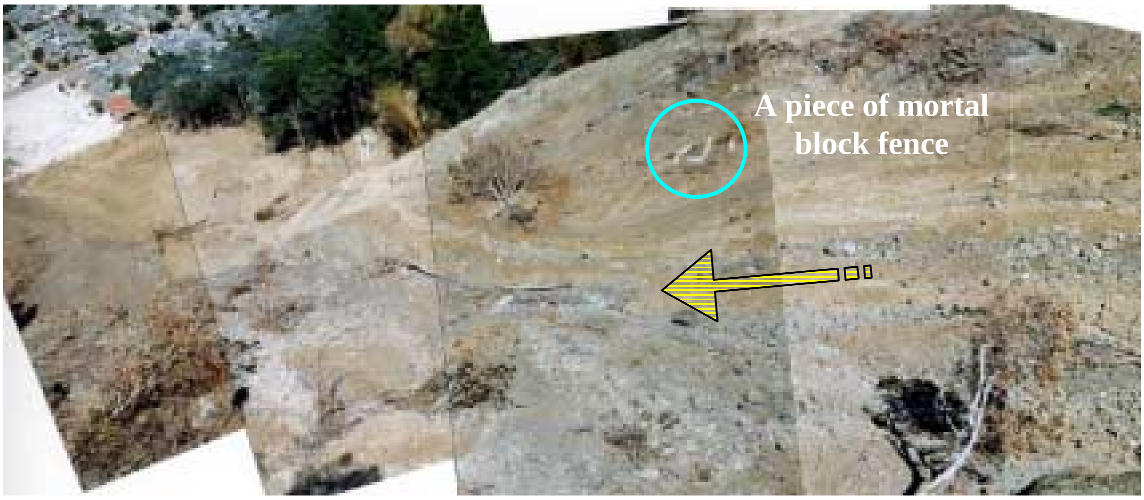


Fig. 1.5 Lower part of the hollow: A piece of mortar block fence (within the circle) is caught on the small amount of the soil mass stopped at the lower edge of the hollow.

Sounding of soil stiffness was done by using a single cone-penetrometer at the western crest of the hollow (**Fig. 1.4** and *Star mark* in **Fig. 1.1(a)**). Thin soft wet layers were found at about 1.2m and 2.5m deep. These two weak layers seem to be pumices and/or fragmental volcanic products, white-yellow-colored light porous volcanic rocks sandwiched in the uppermost part (EL. +1030 - +1076) of the ridge. This part of the ridge is a thick sediment of tephra, with some wet layers of pumice or tuff underlain thin gray less-permeable films. The tephra sediment is overlaid with a stiff tuff forming the top terrace of the slope.

Broken pieces of a mortal-block fence were caught on the soil mass remaining on the outer edge of the hollow, and there are some downward streaks remaining on the bottom of the hollow (arrow in **Fig. 1.5**). These may be evidencing that most soil mass, which originally fitted into the hollow, seems to have been pushed forward, and flown down the lower steep slope.

The 3D configuration of the entire slope was surveyed from three reference points (**Fig. 1.6**). Two ravines coming down from both sides of the slope curve forward and meet at the middle of the slope width. The steepest slope was covered thin with a film of mud including porous fragments of pumice; the film is noticeably stiff after totally dried up. The film covered trees, bamboos and other plants mowed down on the slope (**Fig. 1.7**). This fact suggests that the bottom surface of the slid soil mass was wet, and may have been liquefied (Sassa, 2000), possibly related to some weak tephra layers spreading over less permeable paleosols (http://landslides.usgs.gov/html_files/centrala.shtml).

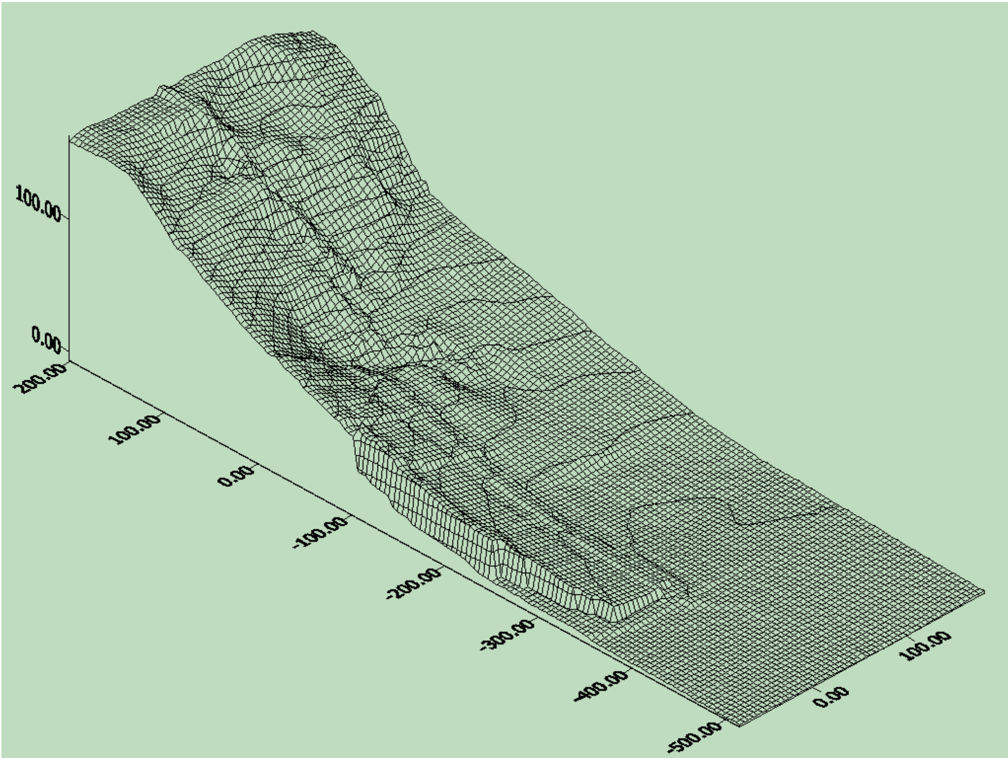


Fig. 1.6. 3D Configuration of the slope
(Contour lines: every 10 m elevation increment)

Fig. 1.8 Thin mud film

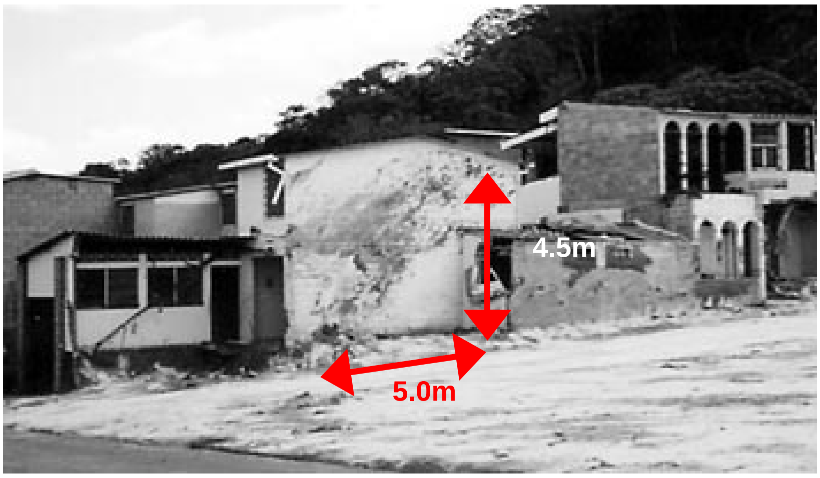


Fig. 1.9. House wall spotting with splashes

There were many splashes of mud remaining on house walls, trees and etc. In general, the splashes seem to be higher at around the toe of the slope than those in the middle or close to the distal end of the soil deposition zone. The highest splash of about 10 m was found on a trunk near the toe. There was water stopped on a pavement. Fig. 1.9 shows the wall of a dwelling on the eastside perimeter of the slid soil mass, the wall spotting in parabola with mud splashes. The parabola with its peak of about 4.5m high drops downward, and reaches the ground after about a 5m horizontal run. This fact suggests that the time *t* needed for the splashes to reach the ground from their peak height Δh (= 4.5 m) was about 1s ($\Delta h = g \cdot t^2 / 2$), and during this time, the splashes ran about the 5m horizontal distance (5 m/s). The main stream of the soil mass flow might have faster than this speed even after running through dwellings standing close together.

(2) Evacuation

Extensive cracks running along the ridge crest are the serious threat of further slides. The city of Santa Tecla is controlling the potential hazard zones, the red zone with the highest risk and the yellow zone of slightly less danger (**Fig. 1.10**). A week after the earthquake, the number of residents evacuated from the zones exposed to the menace of possible landslides reached 14,000, and as of Feb. 3, about 4,000 refugees were still being forced to live in tents (**Fig. 1.11**).

Fig. 1.10. Zones of potential risk

Fig. 1.11. Refugees' camp

(3) Microtremors and Soil properties (Ring-shear Tests, and etc.)

Reports will be put up as they are ready.

1.2 SAN VICENTE LANDSLIDE

At the 53rd km of the Panamerican Highway, in San Vicente, a slid soil mass has blocked the road (**Fig. 1.12, above**). Three dimensional shape of the slip surface (hollow) was measured (**Fig. 1.12 below**), and the possible volume of the slid soil mass was roughly estimated to be about 300,000 m^3. A steeply dipping joint surface seem to have served as a slide plane. Some cracks were found further above the upper end of the scar.

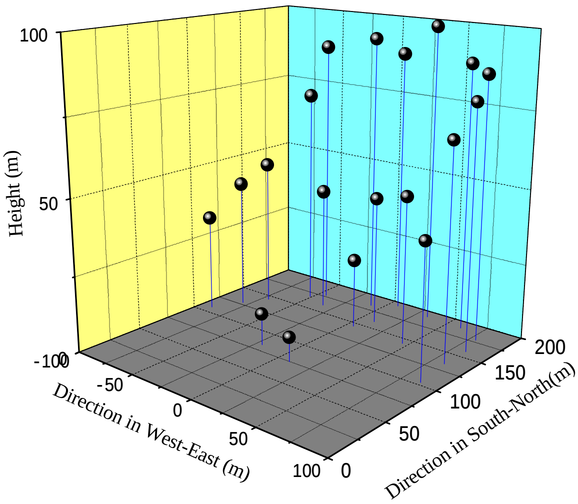


Fig. 1.2 Configuration of San Viente Landslide

Fig. 1.3. Bahareque house near San Vicente landslide: This bahareque house, standing on the terrace high above the headscarp of the slide, performed quite well, though it suffered some diagonal shear cracking.

1.3 POSSIBLE MEASURES

Makeshifts and/or short-term measures:
(1) Crack maps (See. **Fig. 1.3**).
(2) Covering cracks with plastic sheets
(3) Continuous monitoring of crack openings

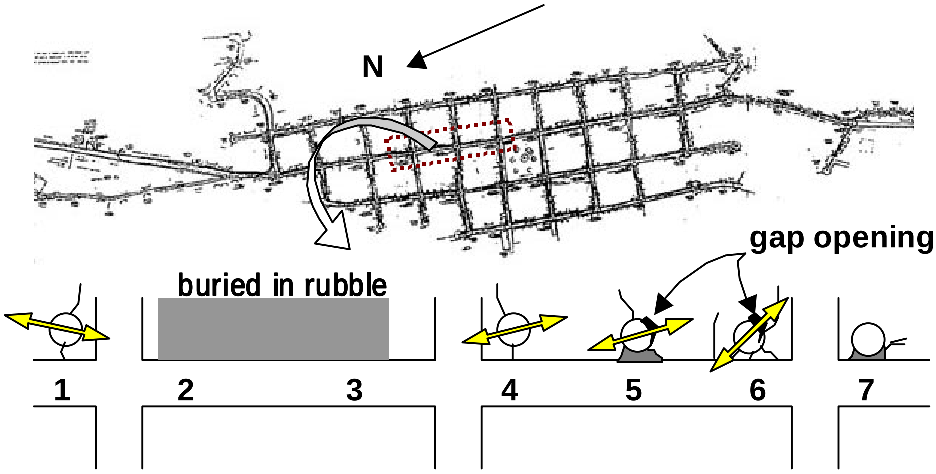
Full measures:
(1) Removing remaining soil masses
(2) Preventive works
(3) Anchoring
(4) Reinforcing with concrete crib arrangement
(5) Piles

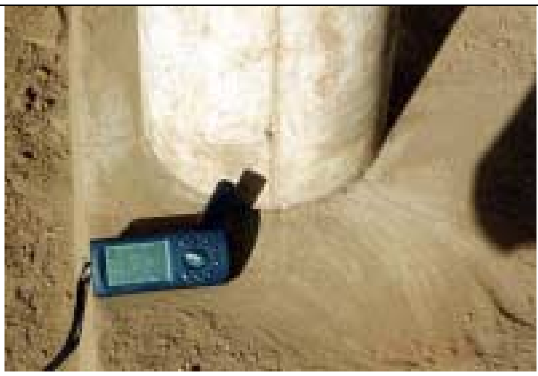
Necessary studies:
(1) Mechanical properties of volcanic sediments (incl. pumice, tuff) must be examined.
(2) Dynamic features of these soils experiencing first alternate and then fast monotonic shear are to be described in terms of some necessary geotechnical parameters,
(3) Possible travel distances of soil masses are to be evaluated.

2. SAN AUGUSTIN

About 90% adobe and un-reinforced masonry houses were flattened in this town (**Fig. 2.2**, next page).

Utility poles (5m tall) are embedded upright in concrete-paved sidewalk. Cracks developing outwardly on the pavement from these poles were mapped. Some poles (**No. 6** and **7**) are very close to the step-shaped edge of the sidewalk. The thin cover concrete thus might have affected the crack pattern. Though the number of the examined utility poles is not sufficient for thorough statistical manipulations, some poles seem to have been forcibly shaken in about N-S direction.





Pole #1

Pole #5

Pole #6

Pole #7

Fig. 2.1. Cracks appearing around utility poles

	
Much of the town was destroyed.	A voluntary person with a white painted clown-like face is amusing children by acting foolish. People there do not have enough tents, and have spent three weeks in the open air, by dusty roadsides since the earthquake.

Fig. 2.2. San Agustin (Feb. 4, 2001)

3. LIQUEFACTION (Railway Bridge crossing the Rio Lempa)

Immediately above the San Marcos Bridge of Carretera Litoral Highway, there is an old railway bridge (1936-) crossing the Rio Lempa (**Fig. 3.1**). The upper deck of the bridge, after the railway was discontinued, was totally asphalt-paved, and served as a route for vehicles. Liquefaction-inflicted lateral spread of soil and associated cracks were found only on the right side of the river (**Fig. 3.2**); the right riverside might have been an old river trace. Fine sands (0.3-0.5 mm) cover thin the ground surface.

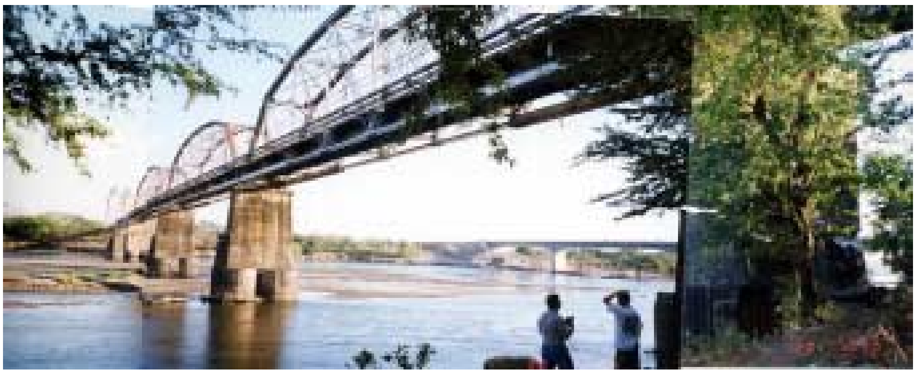


Fig. 3.1. Old railway bridge crossing Rio Lempa

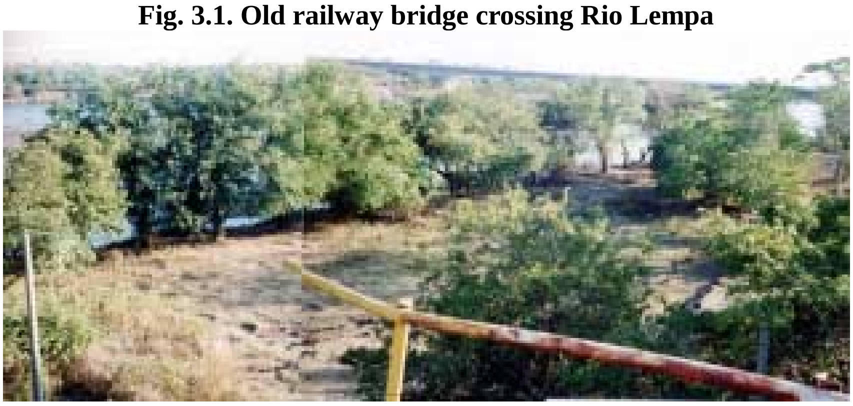


Fig. 3.1. Lateral spread of soil and associated cracks

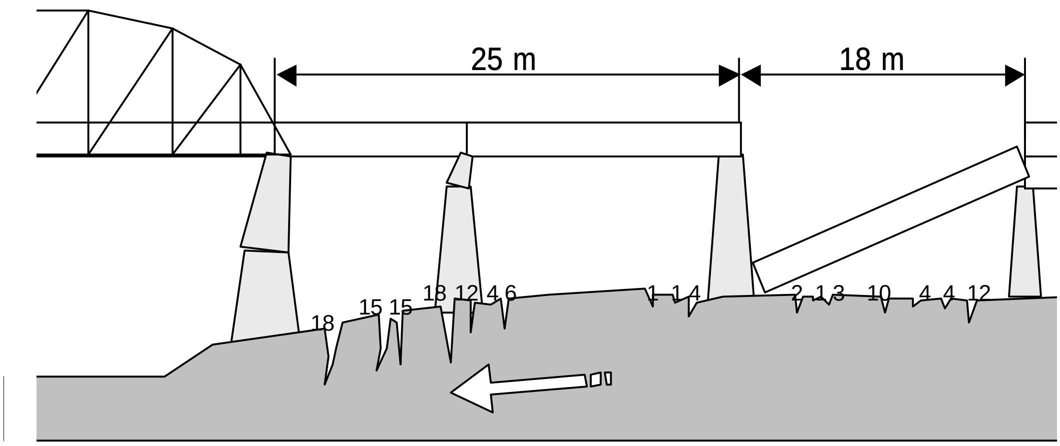


Fig. 3.2. Crack openings (cm)

Visible crack openings were measured (**Fig. 3.2**). Total 1.27 m's opening was reached over the 45 m's distance. Piers (caisson foundations?) supporting truss guiders seem to be stable and stiff. The truss girders propped up the right approach girders, while the lateral flow of soil have carried the lower parts of piers towards the river. → Construction joints opened wide.