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Ground effects caused by the Alto Mayo earthquakes in Peru

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ABSTRACT: On May 29, 1990 and April 4, 1991, two moderate earthquakes occurred in the northeastern region of Peru. Despite their relatively low magnitudes, the severity of the damage was high because of the existing type of construction and soil conditions in the populated areas. The region is located in the peruvian upper jungle, with high precipitation. Sedimentary rocks from the Jurassic to Cretaceous Periods are found in the nearby mountains and Quaternary materials in the Alto Mayo river valley. Quaternary deposits are composed of alluvial, colluvial, fluvial and residual soils. Moyobamba and Rioja are the most important cities in the area. The region is crossed by the Mayo river, whose banks are composed of liquefiable sand deposits. The following earthquake ground effects have been reported: soil liquefaction, instability and soil erosion in the slopes, differential settlements, soil amplification and landslides within the epicentral area. A geotechnical exploration program was undertaken in Moyobamba, Rioja and Soritor cities. The earthquake ground effects are described and a brief summary of the geotechnical characteristics of selected areas in the principal cities is presented.

1 INTRODUCTION

The Alto Mayo region in northeastern Peru was recently struck by moderate earthquakes. On May 29, 1990 at 9.34 pm (local time) an earthquake with a magnitude of mb=6.0 occurred to the southwest of the city of Rioja. This quake caused 70 deaths and damaged 6000 houses of a total of 20000 existing in the epicentral area. Most of the houses were constructed with adobe and tapial. A maximum intensity of VII MMI was observed in Soritor (Alva-Hurtado et al 1990; Huaco et al 1990; Torres et al 1990).

Beginning April 4, 1991, a series of shocks was triggered in the same region. The largest event occurred at 11.30 pm (local time) with a magnitude of mb=6.5. Its epicenter was 30 km northeast of Moyobamba, near Angaisa mountain. The death toll was 40. Heavy damage was caused to property in the provinces of Moyobamba and Rioja. Intensities of VII MMI were observed in Moyobamba, Yantalo and Nuevo Cajamarca. Several persons saved their lives because they spent the night in their backyards or "tambos", due to the alarm produced by the precursor shocks that occurred earlier in the day (Cuadra & Chang 1991).

The Japan-Peru Center for Earthquake Engineering Research and Disaster Mitigation (CISMID) undertook a series of studies in the affected area. Several reports on field reconnaissance, damage evaluation and seismic microzonation of the cities of Moyobamba, Rioja and Soritor have been produced. In this paper a summary of the earthquake ground effects and the geotechnical characteristics of selected areas of the main cities are presented (Chariarse et al 1991; Cuadra et al 1991; Fukumoto et al 1991; Lara 1992).

2 SEISMIC HISTORY OF THE AFFECTED REGION

The seismic history of the area is rather scarse, due mainly to the isolation of the populated areas and lack of good communications. Silgado (1978) has published the seismic history of the peruvian territory from the 16th century to the present time. The most important earthquakes that affected the region under study are described (Alva-Hurtado et al 1984):

- November 26, 1877. The city of Chachapoyas suffered a strong ground motion. Intensity of VI MMI.
- September 28, 1906. Seismic intensity of VII MMI was assigned to Chachapoyas. The magnitude of the earthquake was Ms=7.5.
- May 14, 1928. A noticeable seismic event occurred in northeastern Peru. Chachapoyas suffered almost completed destruction. A landslide in Pinpincos (Chamaya Valley) caused 25 deaths. The magnitude of the earthquake was Ms=7.3. Maximum intensity of X MMI in the epicentral area.
- August 6, 1945. A strong earthquake af-

fected the departments of San Martin and Amazonas. A seismic intensity of VI MMI was reported for Moyobamba. The epicenter was located to the east of Moyobamba. Soil liquefaction occurred in Shango, Tahuishco and Azungue ravines.

- June 19, 1968. A strong earthquake struck the northern part of the department of San Martin, causing the death of 15 people. The magnitude assigned to the earthquake was Ms=6.9 and mb=6.4. Heavy damage in the cities of Moyobamba and Yantalo. The epicenter was located northwest of Moyobamba. Soil liquefaction along the Mayo river banks and around Moyobamba. Maximum intensity of IX MMI.

3 GEOLOGICAL SETTING

The region belongs to the Subandean zone of northern Peru. The rocks outcropping around the Alto Mayo valley are sedimentary continental and marine rocks from the Jurassic to Cretaceous Periods and continental rocks of the Tertiary. These rocks have tectonic folding and overthrusting. The valley has quaternary deposits of fluvio-lacustral origen, overlying the rocks. Test boreholes in the valley have indicated the existence of peat deposits of 20 meters depth.

The type of faulting in the area corresponds to folds and high angle thrust faults that form imbricated systems. These faults have less dip with depth, producing a thrust and fold belt structure. Several of these faults have visible traces and evidence recent activity. Valley scarps can be seen to the west of the Alto Mayo, as well as longitudinal valleys and displaced morphological units, typical of active transcurrent faults. Also, to the north and south of Moyobamba, rectilinear scarps can be seen that could correspond to active normal faults (Martinez & Machare 1991).

The surface geology, as well as the fault traces and epicenters of the 1990, 1991 and past earthquakes are shown in Figure 1.

4 GEOTECHNICAL CHARACTERISTICS

With respect to the geotechnical characteristics of the area investigated, four very distinct types can be distinguished (Kuroiwa & Deza 1968; Martinez-Vargas 1969):

Type I Rocky ground.- The rocks are of sedimentary type: sandstones and siltstones. These rocks surround the Alto Mayo valley. They are indented because of the dentritic drainage existing in the area. The rocks are susceptible, because of their nature and the environmental conditions, to mass movements, such as rocks falls, landslides and slumps.

Type II Residual soils.- They are located over the parent rock and are the product of weathering. In general they have high to medium density (coarse soils) and high to medium stiffness (fine soils). These soils exist in the elevated parts of the cities of Moyobamba and Rioja. The residual soils have medium bearing capacity. There are slope stability problems when the slopes are high, with a steep slope angle and low clay content.

Type III Dense quaternary soils.- They consist of colluvial and alluvial soils with good drainage. Some colluvial soils and terraces contain blocks and gravels in a sandy matrix. These soils are located in the affluent valleys of the Mayo river, in the mountainous areas and in the superficial layers of low gradient terrain. In general, they have good bearing capacities.

Type IV Soft quaternary.- These are mainly saturated fine sands located on the banks of the main rivers and ravines. They are also the interlayered clays, peats and sands of lacustral origen that form the extense plateau of the Alto Mayo valley. In general, this type of soil has poor geotechnical behavior.

The city of Moyobamba was originally built on a stable plateau constituted by residual soils type II. The slopes around the city have erosion problems. The lowlands in Moyobamba, such as Tahuishco, Shango and Azungue have ground type IV. A similar situation exists in the city of Rioja where highlands are residual soils and lowlands are soft soils. However, in Rioja the slopes are more stable. Soritor is located on the right bank of the Tonchima river. Its ground consists of type III soils. There are other cities in the area, such as Nuevo Cajamarca, that are located on soil type IV.

5 GROUND EFFECTS OF THE EARTHQUAKES

The geotechnical types of damage are briefly reported, such as: ground cracking, soil liquefaction, soil amplification and landslides. It must be emphasized that most of the damage had structural origin, i.e. the design and construction with earthen materials. However, those damages will not be included in this paper.

Ground Cracking.- Tension cracks were observed in 1) the crest of the slopes of the Moyobamba plateau, associated with soil liquefaction and lateral spreading, 2) the highways, as tension zones that could develop future landslides and slump, 3) the soft soils in the Mayo river banks. The epicentral area in the mountains was not inspected because of the difficulty in getting there.

Soil Liquefaction.- Soil liquefaction occurred in Tahuishco Port in Moyobamba. Lateral spreading developed in the school in Tahuishco in 1991 with cracks 10 cm in width and 50 cm deep. One classroom floor was destroyed. In 1990 the phenomenom did not reach the school building, but did occur in the school yard; sand volcanoes also appeard in the school yard. During both earthquakes, segments of the highway between Moyobamba and Tahuishco were damaged.

In Azungue, located in the lowlands of Moyobamba, ground cracks and lateral spreading developed. Cracks 100 m long and 40 cm wide with depths of 1 m were reported. Most of the houses on the slope collapsed. The sewage pumping station and sewage disposal pipes failed. All tapial houses and some masonry houses on soft ground collapsed. In Shango, tapial houses collapsed. Cracks 80 m long and 20 cm scarps were observed. In Miraflores street the cracks were 30 m long and 30 cm deep. During the 1990 earthquake soil liquefaction was reported in El Chorro and Molino Valencia in Rioja, also in Segunda Jerusalen-Azunguillo, Negro river and La Conquista.

Soil Amplification.- Considering the geotechnical characteristics of the soft soils consisting of clays, peat and silts in the lacustral and fluvial deposits of the Alto Mayo valley, it is suggested that local soil conditions have played a major role in the damage of structures as well as the ground cracking. Soil amplification could have occurred in Nuevo Cajamarca, Naranjos, Segunda Jerusalen, San Fernando, Yuracyacu, etc.

Landslides.- Several types of mass movemets were produced during the 1990 and 1991 earthquakes.

Rockfalls.- They occurred on steep slopes having elongate prints, with heights of 50 m and widths of 30 to 40 m in fractured sandstones, limestones and residual soils. Mainly in unpopulated areas.

Translational slides.- These were present in the borders of the Moyobamba plateau, in sandy materials without fines and steep slope. This type was reported to the north and east of Moyobamba, in Punta San Juan, Punta Tahuishco, and Cococho district. The heights were as much as 30 m.

Rotational slides.- These were observed at Km 500 of the Marginal highway for both earthquakes. The slides is related to a colluvial deposit resting on soft ground. The damage to the highway was 70 cm long.

Soil block slide.- In Punta Tahuishco this type of slide was observed. The block consists of silty sands 60 meters wide. The crack was 5 cm maximum width and 7 cm scarp.

Lateral spread slides.- They developed in areas of low gradient, where the subsoil consists of sand and silt and soil liquefaction was evident. Tahuishco and Azungue (Moyobamba) reported such slides.

The ground effects previously described, that were caused by the Rioja (1990) and Moyobamba (1991) earthquakes in the Alto Mayo region, are depicted in Figure 2, which is an update of the figure presented in Monge (1990). In Figure 3 are presented the earthquake ground effects in the city of Moyobamba. The subsoil in the lower parts of the city, such as Tahuishco, Azungue and Shango consists of fine sands and silty sands with low relative densities and high water level. The soil in the slopes is constituted mainly by clayey and silty sands with medium densities and relatively low water table, whereas the ground in the elevated part of the city (plateau) consists of clays and clayey sands of medium to low bearing capacities and deep water table. Seismic intensities in the lower part where two degrees higher than in the elevated part of the city of Moyobamba.

6 CONCLUDING REMARKS

1. The seismic history of the Alto Mayo region indicates that the seismicity is very high. It is necessary to undertake detailed studies of the active faults existing in the area.

2. The earthen type of construction prevalent in the affected zone, adobe and tapial, is the main reason for the heavy damage; however, the ground characteristics also contributed to the damage. There is a direct relationship between damage level and soil conditions.

3. In the lowlands of Moyobamba and Rioja, with loose sands and high water table, soil liquefaction occurred and contributed to the building damage.

4. In the lacustral area, with soft soils, such as Nuevo Cajamarca, the phenomenom of soil amplification developed.

5. Slope inestability was generated during the 1990 and 1991 earthquakes in the Alto Mayo region. In Moyobamba and Rioja soil slumps were produced, in connection with problems of erosion. Landslides in the high mountains did not affect the population. Rotational slides damaged highways and canals.

6. During the earthquakes no strong motion records were obtained; there were no nearby seismographs. It is recommended instruments to be installed in the area.

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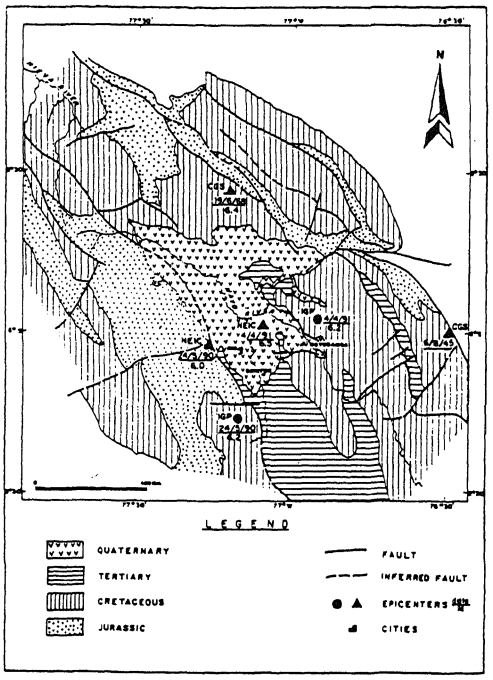

Figure 1.- Geological and seismotectonic map of the Alto Mayo region

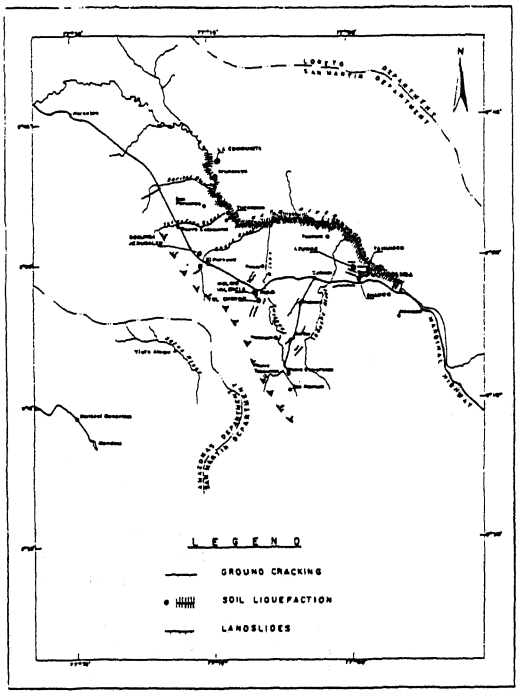

Figure 2.- Earthquake ground effects in the Alto Mayo region

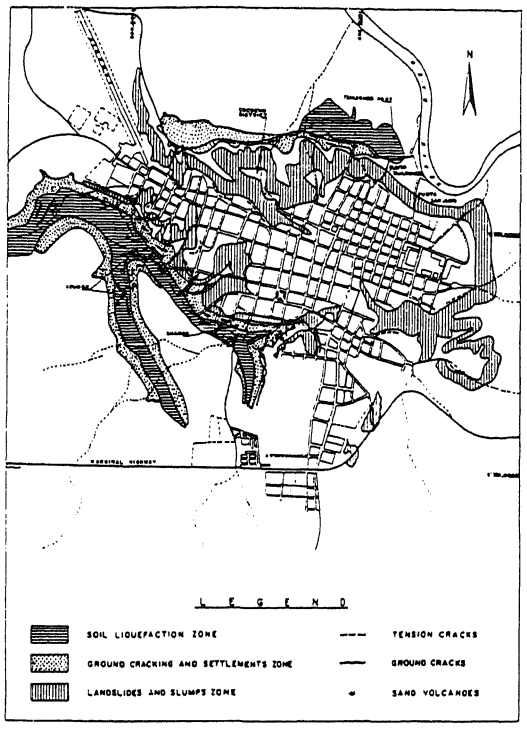

Figure 3.- Earthquake ground effects in Moyobamba city