3. GEOTECHNICAL ASPECTS

3.1. Introduction

The most spectacular geotechnical aspect of the 2007 Peru Pisco earthquake was the damage caused by the liquefaction and accompanying lateral spreading, not only in Tambo de Mora (section 3.4), but also in the parts of Pisco closest to the ocean (section 3.5). In the northern part of the affected area, close to Canete, several large ground cracks were observed and they are described in the next section. A common and important problem in this earthquake is the lack of foundation reinforcement in important public buildings or complete lack of foundations for adobe houses, both reducing considerably the earthquake resistance. Furthermore, due to the lack of foundation, many adobe houses have very humid walls, which is health problem in itself. The slope failures and landslide we visited caused damages to roads and are therefore described in the road damage chapter.

3.2. Large soil cracks in San Luis

In the San Luis annex Nuevo Monte Rico, several large and long ground cracks were observed in an area of 1km^2 size. Fig. 3.1 shows view from Google earth of the location of the ground cracks and Fig. 3.2 shows geology the same area. Nuevo Monterrico is located on an alluvial plain, shown as green areas in Fig. 3.1, and as whitish color with open circles in Fig. 3.2, are spreading between granitic formation in the North at San Francisco (in Fig. 3.1) and a tertiary sandstone formation (Paracas Formation) in the south. The ground cracks cause by damage to buildings, agriculture, and also, according to the local people, 3 wells went dry in the area. We do not know presently if the cracks were caused by liquefaction induced lateral spreading, or if large scale tectonics might have created extension in this area. Such extension often occurs on the continental plates in subduction zones. This needs to be investigated further. Below follows a more detailed description of the cracks and related damages

Fig. 3.1. Google earth view of San Luis Annex Nuevo Monte Rico. GPS coordinates next to right yellow point shows location of large cracks.

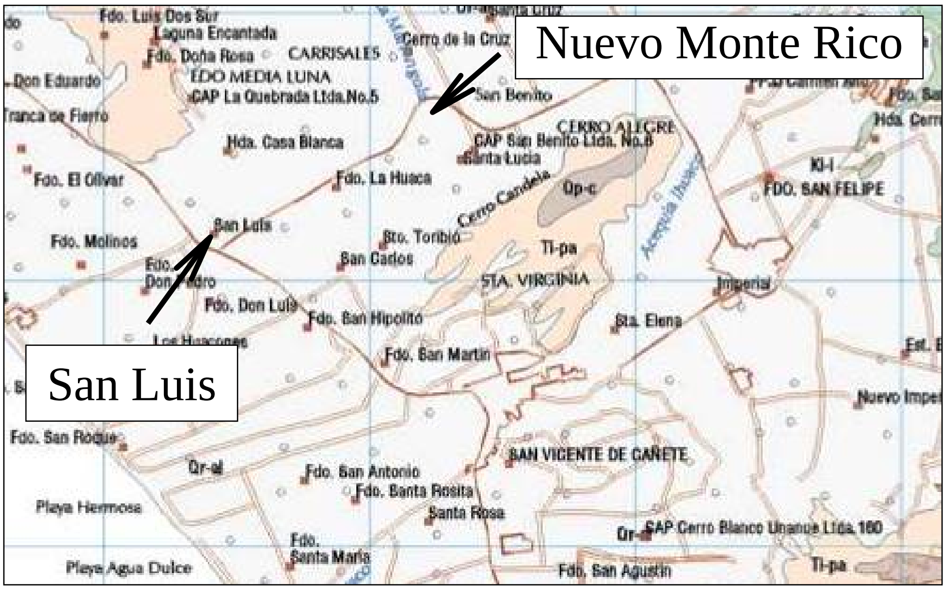

Fig. 3.2. Geological map (INGEMMET) view of San Luis Annex Nuevo Monte Rico.

There are 3 clusters of cracks in Fig. 3.3. The first cluster of points 37 to 40 indicated smaller lateral spreading failures along the dirt road (road 746) leading from the Pan-American Highway to Nuevo Monte Rico. There was drainage ditch on the north side of the road towards which lateral spreading occurred over a length of over 200 meters. On the south side of the dirt road there was a sewage pipe, leading from Nuevo Monterrico towards the ocean, which broke, likely due to the lateral spreading, and related soil displacement induced a lot of cracks in the cotton field next to the road (see Fig. 3.4). These cracks cause a lot of trouble for the farmers to irrigate their fields, since the water went into ground through the cracks, instead of being distributed through small irrigation canals to the whole field.

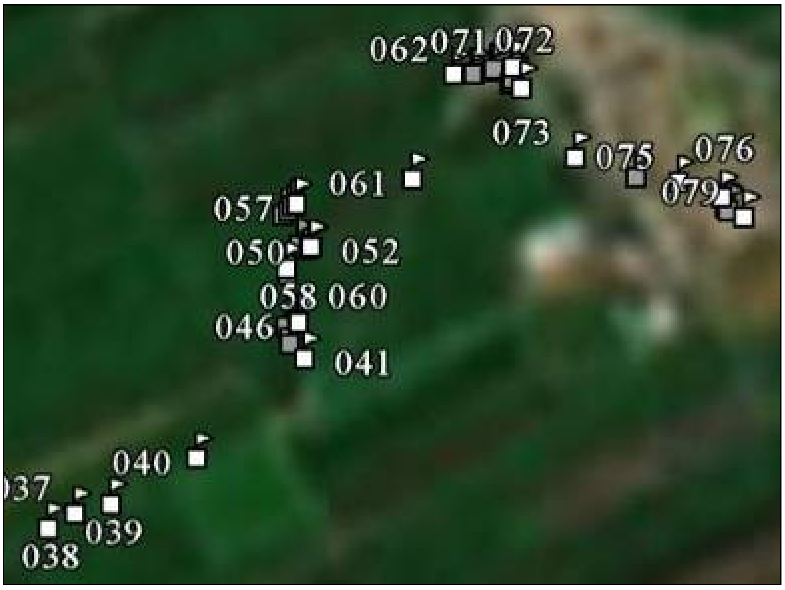

Fig. 3.3. Google earth view of San Luis Annex Nuevo Monterrico with GPS points.

Fig. 3.4. Cracks in cotton field causing trouble for the farmers to irrigate their fields.

At the cluster of points 40-44 in Fig. 3.5, an approximately 70 meter long crack were found. A close up is shown in the map in Fig. 3.6 and photo in Fig. 3.7. Another shorter crack was also found nearby, at point 46 in Fig. 3.5, with large vertical offsets of up to 40 cm (see Fig. 3.8). There were some indications of liquefaction since soil seemed to have been fluidized and finer grains settled on the top, but we saw no clear sand boils in the area. These "liquefaction traces" might have rather been due to irrigation of field in the weeks after the earthquake. Some of the fields in this area had already been plowed so many cracks had been erased. This shows how important it is to get into the field directly after the earthquake hit.
Another farmer had also irrigation problems in an apple plantation at GPS point 57 in Fig. 3.5. due to large cracks (see Fig. 3.9)

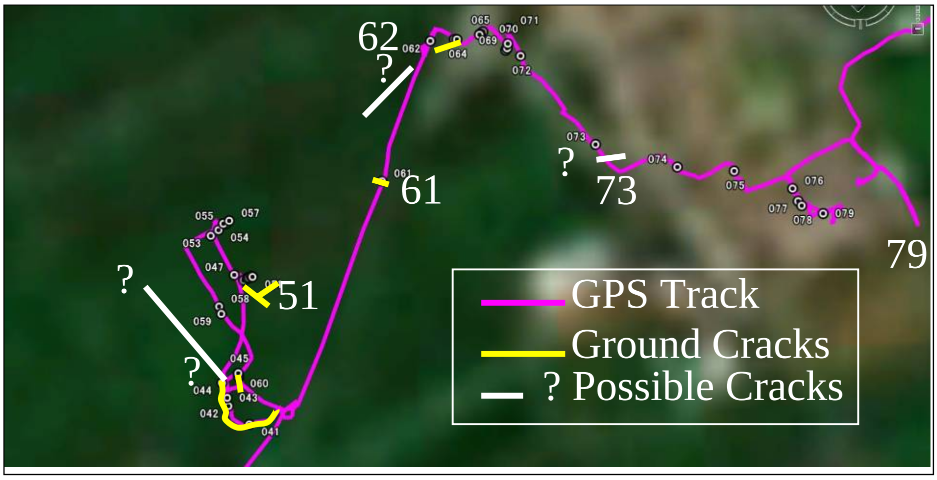

Fig. 3.5. Google earth view of San Luis Annex Nuevo Monterrico with GPS tracks in purple. Yellow shows location of large cracks. White shows location of cracks reported by local people. White colored crack located close to point 62 we observed from the road only.

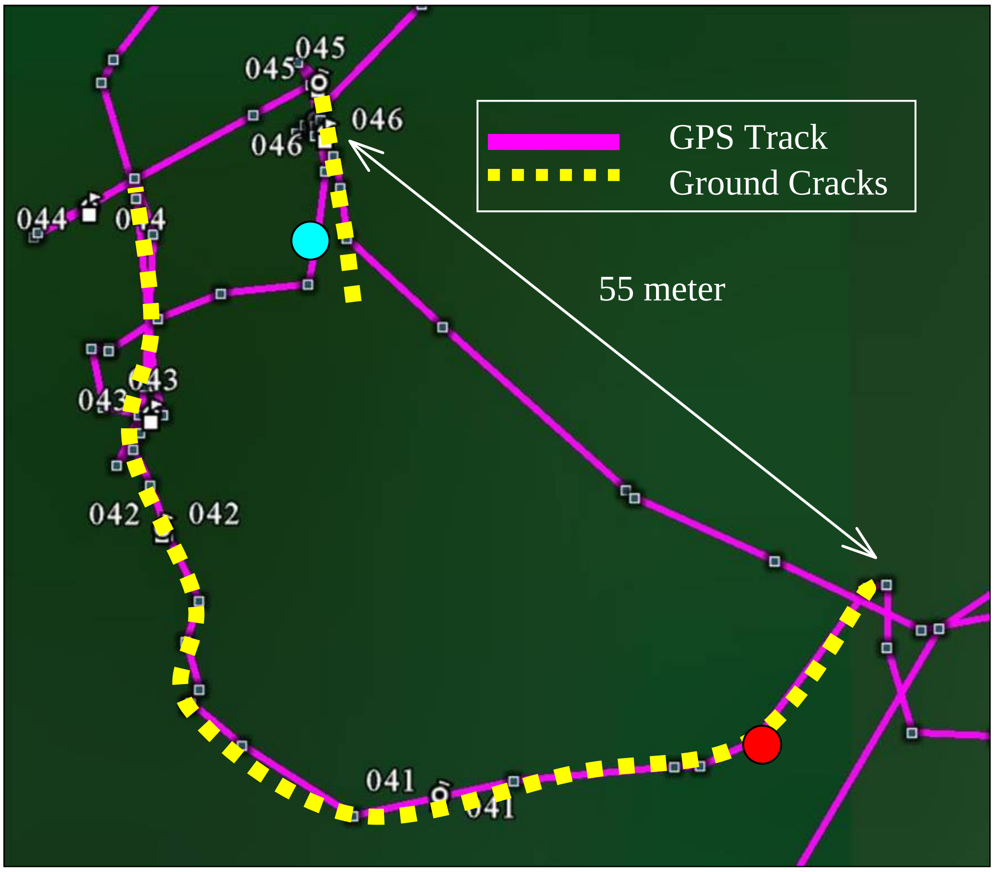

Fig. 3.6. Close up of ground cracks and GPS tracks at point 41-46. Photos taken at light blue dot and red dot are shown in Fig. 3.7 and Fig. 3.8. Cracks were some 70 meters long.

Fig. 3.7. Photo of large ground cracks at GPS points 41-46 in Nuevo Monterrico agriculture field. (Photo taken at red dot in Fig. 3.6.)

Fig. 3.8. 40 cm offsets of ground cracks in Nuevo Monte Rico agriculture field. (Photo taken at blue dot in Fig. 3.6.)

Fig. 3.9. Apple plantation ground cracks in Nuevo Monterrico. (Photo taken at point 51 in Fig. 3.5.)

More ground cracks were scattered further NNW, at point 61 there were cracks in the road and also at point 62 where the cracks damaged some houses (see Fig. 3.10). At our visit in this area many ground cracks were already gone and we relied upon local people stories and our own judgment. Fig. 3.11 shows a collapsed adobe house possibly due to large ground cracks; A local construction company person told us the crack crossed the street and reach the adobe house. Noting that the adobe wall to the left was not damaged it is possible that the damage of the right part was due to the crack and less due to shaking. However this needs to be confirmed.

Fig. 3.10. Large ground cracks in Nuevo Monterrico crossing road at point 61 with destroyed houses in the back ground.

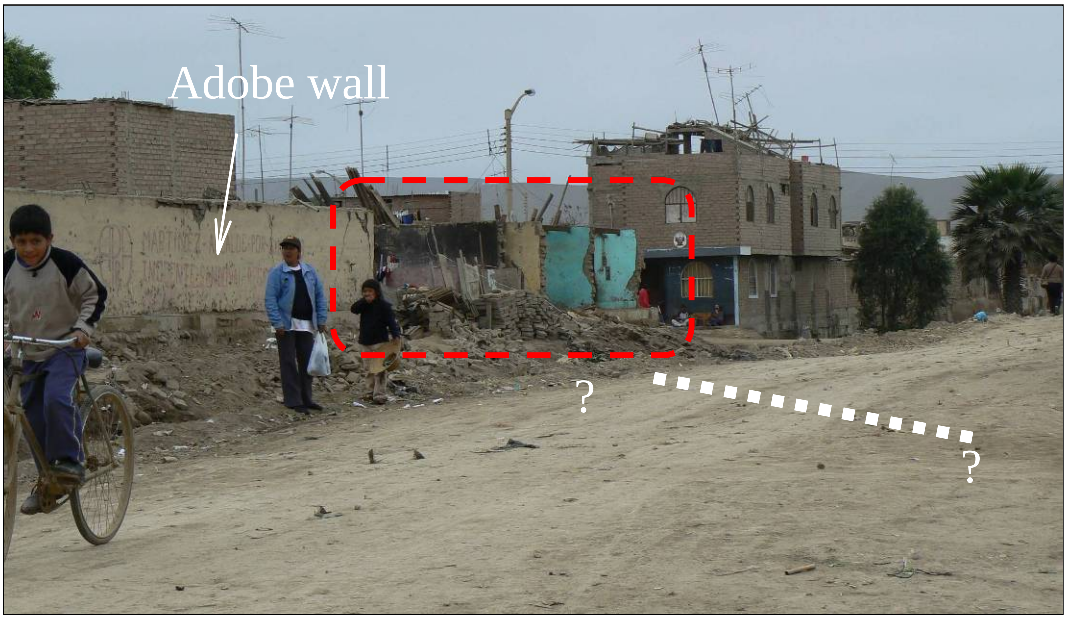

Fig. 3.11. Collapsed adobe house due to large ground cracks in Nuevo Monterrico. The local people told us the crack crossed the street. The adobe wall to the left did not collapse.

Fig. 3.12. Damage house located at point 79 in Fig. 3.6.

3.3. Foundation aspects

3.3.1. Health center in Huaytara

Huaytara is located some 130 km away from the epicenter, high up in the mountains. Here the ground shaking was not so severe and mainly vertical cracks in adobe walls were observed. One of the church towers suffered damage as well. A damaged school building is described in Chapter 4.

The health center in Huaytara suffered cracking of walls due to a foundation problem. At the construction there was a sewage canal, which is not in use any more, and on top of which an unreinforced foundation slab was placed. Due to the earthquake there was some soil movement around the canal and there was uneven settlement of the slab, causing it to crack as seen in Fig. 3.14.

Fig. 3.13 Health center in Huaytara with cracks in walls due to foundation differential settlement.

The health center was built on a slope, which likely exaggerated the soil movements and their effects on the slab foundation.

Fig. 3.14. Huaytara health center foundation slab with 1cm wide crack due to differential settlement.

3.3.2. Adobe foundations and ground humidity an example from Guadalupe

Guadalupe is located on kilometer 290 of the Pan-American Highway. There was a lot of damage to adobe house in this area ranging from completely collapsed house to houses with cracked walls. There was greater amount of damaged houses on the east side of the Pan-American Highway, possibly related to higher moisture content of the soils weakening the adobe walls. The adobe walls absorb the moisture from the surrounding ground, which thereby softens the mud bricks. This problem is wide spread in many locations in Peru and likely in other countries as well. The moisture absorption was evident inside one house as shown in Fig. 3.15.

Fig. 3.15. Foundation problems in Guadalupe: Miscoloring due to moisture absorption by adobe wall. The moisture weakens the structural properties of the wall, thereby the earthquake resistance of the house, and it also constitutes general health threat.

A typical foundation method for the adobe houses consists excavating a narrow trench and putting the adobe blocks inside trench, right on top of the soil. With time the buried part of the adobe wall absorbs moisture becomes soil again, i.e. the wall is virtually placed on the ground. It is questionable if it is of any help to excavate the trench in the first place. An example of such a wall is shown in Fig. 3.16. The moisture also accelerates decomposition of organic materials within the adobe blocks, further reducing the strength of the blocks, since the organic materials function as sort of “fiber reinforcement”. In addition to reducing the earthquake resistance of an already earthquake vulnerable building type, the moisture also constitute a general health problem. With the above in mind it is necessary to convey the message of proper foundations preventing moisture to be absorbed in the walls. The adobe moisture absorption is a big problem in the “Barrios Altos” area in Lima and the vulnerability of these houses will show itself in the next big earthquake in Lima.

In the northern part of Ica a drainage dike was constructed to drain the soil in the area (according to local engineer), but due to the suspended material entering, the dike clogged up and the drainage capacity was reduced drastically. Proper maintenance of these civil infrastructure is thus important.

Fig. 3.16. Temporary self-built house. The original house collapsed in the earthquake. The dashed box shows how the lower part of the wall is darker due to moisture absorption.

3.3.3. Good performance by two liquefaction resistant buildings in Pisco

We found two buildings with good performance even though damage to buildings around them was severe. The location is indicated in Fig. 3.17. This area was severely damage by liquefaction as seen in the ground cracks in Fig. 3.18. Lateral spreading caused the soil to displace towards the ocean and the creating some 10-15 cm wide cracks in the soil. The crack probably continues in front of and/or beneath the blue building and then up through the confined masonry wall as marked by the black arrow in Fig. 3.18. The soil settled some 10-15 cm next to the blue house as shown in Fig. 3.19.

Settlements and cracks like these caused by the liquefaction damage in many houses in this and other areas of Pisco.

Fig. 3.17. Google earth satellite view of location of buildings with pile foundation (blue mark) and strong foundations slab (green mark).

Fig. 3.18. Soil displacement crack next to old building. (blue mark in Fig. 3.17). The crack probably continues in front of and/or beneath the building and then up through the confined masonry wall as marked by the black arrow. (The curvature of the building top is due image distortion, it should be a straight line.)

Fig. 3.19. 10-15 cm soil settlement around blue building on pile (?) foundation. Blue mark in Fig. 3.17

The old building was hybrid structure with confined masonry to the right and left as seen from the ocean side in Fig. 3.20. The central part is made of wood and stands on an elevated pile foundation. The small stair to the left in Fig. 3.20 came partially off the building due to the lateral displacement, but otherwise the building performed seemingly well.

Fig. 3.20. Old building located close to the ocean in Pisco that performed well even large liquefaction displacement was observed. In the central part a pile foundation is visible.

Fig. 3.21 shows a close up of pile foundation with corroded reinforcement bars. The age of building foundation is unknown, but many of the buildings in here were constructed 50 to 100 years ago, in connection with the establishment of the fishing industry here.

Fig. 3.21. Close up of pile foundation showing corroded reinforcement bars. The age of building foundation is unknown, but many of the buildings in these area were up to 100 years old.

On the opposite side of the street away from the ocean there was a recently completed hotel that was about to open. It suffered only minor damages due to that its strong reinforced foundation could resist the liquefaction effects. A close up of hotel damage is shown in Fig. 3.23. Relative ground movement, due to liquefaction, between the columns of the exterior roof structure and the building, caused the cracks. In general well engineered structure like this one suffered only minor or no damage.

Fig. 3.22. New hotel which suffered only minor damages. A close-up of the part inside the red dashed box is shown in Fig. 3.23