DAMAGE IN AREAS AFFECTED BY THE AUGUST 15, 2007 PISCO EARTHQUAKE, PERU*

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ABSTRACT: On August 15, 2007 at 18:41, a large earthquake (Magnitude, Mw=8.0) hit the central part of Peru's coast, some 150 km south of Lima. 519 deaths, 1,291 injured, and more than 200,000 people were reported by the Civil Defense Institute as of October 2007. Liquefaction caused severe building and housing damage in Pisco and Tambo de Mora. The Pan-American Highway also suffered from liquefaction damage and damage to the Huamani Bridge. Reinforced adobe houses performed very well. In collaboration with the Japan-Peru Center for Seismic Investigation and Disaster Mitigation (CISMID) we evaluated ground conditions by measuring ambient vibrations in Pisco to support the on-going reconstruction efforts.

Key Words: Pisco Earthquake, liquefaction, adobe, confined masonry

INTRODUCTION

On August 15, 2007 at 18:41, a large earthquake (Magnitude, Mw=8.0) hit the central part of Peru's coast, some 150 km south of Lima. The Peru Geophysics Institute (IGP) estimated Modified Mercalli Intensities of VII-VIII in Pisco, Chincha, and Ica. The earthquake tragically resulted in 519 deaths, 1,291 injured, and more than 200,000 people affected as of October 2007. Totally, some 80,000 dwellings and buildings were damaged or completely destroyed in the regions of Ica, Lima, Huancavelica, Ayacucho and Junín [1]. Due to the event large magnitude and the heavy damage, the Japan Society of Civil Engineers (JSCE) and the Japan Association of Earthquake Engineering (JAEE) decided to support the dispatch of a joint team together with the Institute of Industrial Science at the University of Tokyo. The objectives of the mission were to investigate damages to dwellings and buildings, considering both structural and geotechnical aspects, and applying the findings to disaster mitigation and reconstruction strategies.

SEISMOLOGICAL ASPECTS

The Mw 8 class Pisco earthquake was caused by the subduction of the Nazca Plate beneath the South American Plate. The duration of the earthquake was very long with over 2 minutes of strong ground shaking at Ica (Figure 1). The local/Richter magnitude computed by IGP was 7.0 (M_L). The epicenter location, close to the cities of Chincha and Pisco, was determined by the IGP [2], University of Harvard [3], and USGS/NEIC [4] as shown in Figure 2. Its depth was reported as 39km (USGS), 33.3

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* Most of the report was taken from the JSCE/JAEE Report on the earthquake prepared by the authors.

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km (Harvard), and 26 km (IGP). The highest recorded Peak Ground Acceleration (PGA) was 488gals at Parcona, Ica. In Lima, the capital city located approximately 150 to 200km from the epicenter, recorded accelerations varied between 20 and 100gals depending on the soil conditions at the recording stations. Intensities in the hardest hit areas were VII-VIII in the Modified Mercalli scale according to the IGP [2].

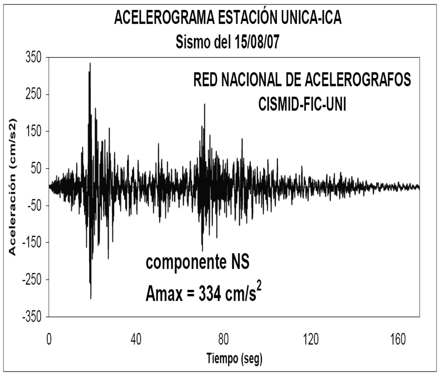

Figure 1. Strong ground motion recorded at the San Luis Gonzaga University in Ica (Courtesy of CISMID)

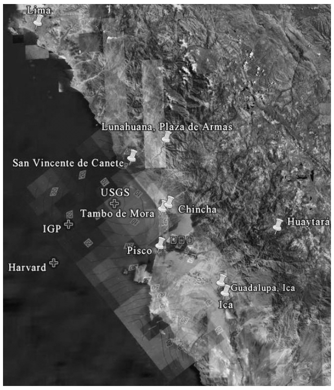

Figure 2. The epicenter location from IGP, University of Harvard (CMT), and USGS/NEIC differs by some 10 to 20 kilometers. (Google Earth map).

GEOTECHNICAL ASPECTS

The most remarkable geotechnical aspect of the 2007 Pisco Earthquake was the damage caused by the liquefaction and accompanying lateral spreading, not only in Tambo de Mora (Chincha Baja), but also in the parts of Pisco closest to the ocean. Tambo de Mora is located on an alluvial deposit in the south and a marine deposit in the north (see Figure 3) and to the east of the marine deposit lies the Pleistocene Canete formation consisting of alternating layers of sand and silt stones [5]. Ground water

Figure 3. Google earth image of Tambo de Mora. The dots mark the limit between formations.

Figure 4. On the border between the Canete formation and the marine deposit, there is a 3 meter differential vertical offset.

Figure 5. Settlement of 0.7 m of building in front of palm tree.

level is very shallow in the marine deposit, surfacing at some locations. In the northern part, a lot of over 20 meter long cracks with grayish sand ejecta were observed. Cracks and up to 3 meter differential settlements (see Figure 4) were seen closer to the Canete formation. Here, light brown/beige seemingly liquefied soil covered parts of some of the vertical scarps. The liquefied area extends from the central park (Plaza de Armas) of Tambo de Mora all the way to the Pan-American highway in the north, which is distance of more than 7 km.

Settlement of buildings and foundation damage due to liquefaction induced ground failure and lateral spreading, caused the collapse of adobe houses and severe cracking of walls of confined masonry buildings. At Canchamana in the northern part of Tambo de Mora, a masonry community building (Figure 6) was severely damaged by lateral spreading and an adobe school building was partially collapsed, while a newer school building with proper foundation behaved well. The Chincha Prison, located North of Tambo de Mora, suffered extensive damage due to liquefaction. The surrounding wall collapsed (see Figure 7) and the prison cells exhibited large settlements. Due to the risk of additional damages, the local government decided to set free the prisoners. This fact suggests that location of this public building deserve further review since the social consequences of its failure were also considerable. A common and important problem in this earthquake was the lack of foundation reinforcement in important public buildings or complete lack of foundations for adobe houses, both reducing considerably the earthquake resistance.

Figure 6. Severely damaged community building in Canchamana,
with liquefaction traces in the foreground.

Figure 7. Collapsed wall at Chincha Prison due to large ground deformation

Evidences of soil deformation were clearly seen along the coast at Pisco. It also affected some buildings and other constructions in the city. Areas close to the coastline particularly suffered extensive damage due to the shake but also, to the effects of the tsunami that hit the area minutes later. The sewer system in Pisco, whose conditions were already poor before the earthquake, was drastically affected due to ground deformation and liquefaction. As shown in Figures 8 and 9, central and northwest areas of Pisco had broken sewer pipes due to ground settlements and dislocated manholes were wide spread.

Figure 8. Central Pisco. Settled ground as evidence of broken sewer pipes.

Figure 9. Manhole pushed up and surrounded by ejected fine sand, northwest of Pisco

Shaking is not the only cause of earthquake damage; permanent ground deformation can also cause extensive damage. In the San Luis annex Nuevo Monterrico, several large and long ground cracks were observed in an area of 1km^2 size. Nuevo Monterrico is located on an alluvial plain spreading between a granitic formation in the north at San Francisco and a tertiary sandstone formation (Paracas Formation) in the south [5]. The ground cracks caused damage to buildings, agriculture, and also, according to the local people, three 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 near subduction zones. The effects of such deformation and cracks need further investigation.

Figure 10. Photo of large ground cracks in Nuevo Monterrico agriculture field.

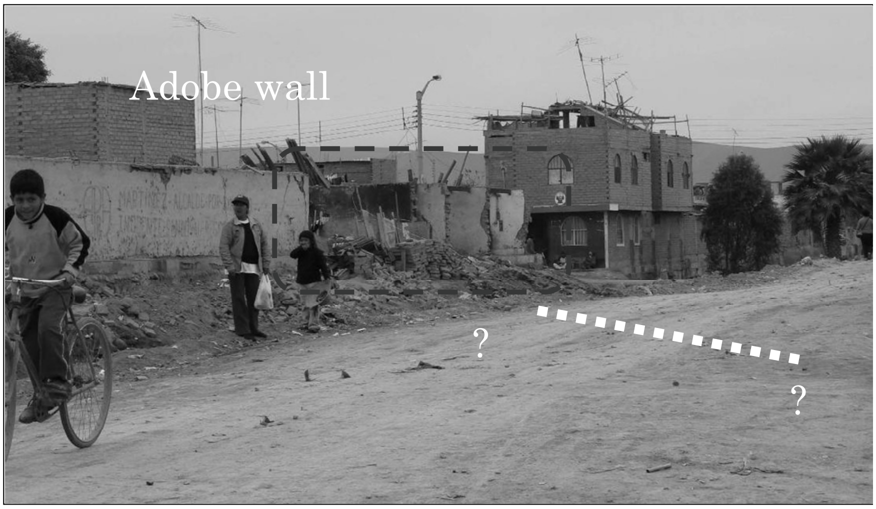

Figure 11. Collapsed adobe house due to large ground cracks in Nuevo Monterrico. The local people told us the crack crossed the street. The adobe wall to the left did not collapse.

BUILDING DAMAGE

Damage to adobe houses, i.e. made of sun-burned bricks, was widespread and may be categorized, in order of severity as: plaster spalling, wall separation, corner collapse (see Figure 12), partial collapse of walls and total collapse of walls (see Figure 13). Important factors increasing the vulnerability of adobe structures were: wall slenderness, construction age, and roof layout. Walls supporting light roofs, which are predominant in the region, were less likely to collapse than those not supporting it due to the restrain at the top that the roof joists provided them. It was observed that in many locations, these houses did not have any foundation. This contributed to the moistening of the walls, where the ground water table was high, with the consequent strength reduction. A few reinforced adobe houses were surveyed at Ica, Lunahuana, and Pacaran. All of them performed very well.

Confined masonry houses designed and built according to the building code did not suffer major damage. All the damaged structures had some type of deficiency. The most common were the use of bricks with horizontal alveolus (hollow bricks) for load bearing walls (locally called *pandereta* and prohibited by the code in this region, see Figure 14), lack of confinement of parapets and façade walls, insufficient wall density, badly distributed stiffness (in plan and elevation), and a poor understanding of the confined masonry construction procedure. Another deficiency was the lack of steel reinforcement in the confining beam or the lack of confining beams altogether.

Figure 12. Corner collapse in adobe house (San Luis, Canete)

Figure 13. Collapsed adobe house (Nuevo Monterrico, Canete)

Figure 14. Load bearing wall made of *pandereta* bricks and poor steel reinforcement in the confinement (Pisco, Ica)

Figure 15. Collapsed façade wall due to lack of confinement (Sunampe, Chincha)

Figure 16. New Emergency Building suffered no damage (San Juan de Dios Hospital)

Figure 17. Concrete block wall collapsed out-of-plane (San Juan de Dios Hospital)

Public facilities, both governmental and private, performed badly in the 2007 Pisco Earthquake. Figures 16 and 17 show the conditions of the San Juan de Dios Hospital after the earthquake. This facility, which is responsible for the health requirements of approximately 125,000 people, was mostly constructed in the 30's with reinforced concrete and concrete blocks. These structures did not performed well during the earthquake and were either demolished or in process of demolition during the field survey. Two new buildings made of RC were completed in 2007 (Figure 16) suffered no damage suggesting the appropriateness of the current seismic code.

At least 640 school classrooms were destroyed and a similar number were affected. In general, the design/construction quality of the schools visited during the survey was very varied. For example, at Los Molinos in Ica, a very new and well constructed school was found next to another which obviously did not followed any design or construction standard. Figure 18 shows one of this building walls in which it is seen that columns in the 1st floor are not aligned with the columns in the 2nd floor. Furthermore, one of the columns is interrupted. Many classrooms made of non reinforced adobe were also found as well as schools built in places unsuitable for construction due to poor soil conditions,

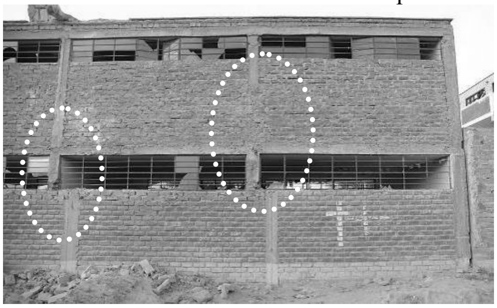

Figure 18. Bad construction example in Los Molinos, Ica

Figure 19. San Clemente Church (Pisco)

such as Tambo de Mora marine deposits. Although it is difficult to control informal housing construction there, public buildings, especially schools should never be built in these places. It is worth mentioning that at many schools, non-structural measures to mitigate earthquakes, such as pasting adhesive tape to the glasses, were observed

This survey did not focus in surveying churches in detail. However, it was obvious from our field work that these structures suffered severe damage. Reportedly, more than 30% of the fatalities due to this earthquake were caused by the collapse of the San Clemente Church in Pisco. In this church, only the portion which had been rebuilt recently did not collapse. A block away from it, only a couple of the 850mm-thick adobe walls of the Compania de Jesus Church were left standing.

ROAD DAMAGE

The Pan-American Highway runs parallel to the coastline and crosses Peru from north to south. The South stretch which is located in the earthquake affected areas had widespread damage mainly due to landslides, rock falls, lateral spreading, and liquefaction as shown in Figures 20 and 21.

This stretch was given in concession on 2005 for 30 years. The concessionary has among its responsibilities to repair and replace the damaged infrastructure after a disaster to fully restore the service within 15 days. Although traffic was briefly disrupted, 5 hours after the event restricted transit was possible and within 48 hours fully traffic was reestablished. Most of the repair works, except for the reparation of the Huamani Bridge located just at the entrance of Pisco, were finished two weeks after the earthquake. This was a critical fact, considering that South Pan-American Highway is the main access to the affected area, especially for the aid coming from Lima city.

The 136-m long Huamani bridge was the largest structure of this type in the earthquake affected area. Two rather slender abutments (typical Base/Height = 0.3), and four intermediate pillars are supported on 5.4m-deep, and 7.3m-deep caissons, respectively. According to the bridge drawings, there is no connection between the abutments/pillars and the caissons. The bridge superstructure is supported on fixed and movable bearings as shown in Figure 22. The southern abutment tilted towards the north causing settlement and cracking of the embankment. Intermediate pillars also rotated. Although the north abutment was not as damaged as the southern, settlement of the backfill was observed there. The geological formation at the bridge north access belongs to the Miocene/early Pliocene age whereas alluvial deposits are found in the south.

Figure 20. Slope failure caused by liquefaction induced lateral spreading

Figure 21. Liquefaction induced embankment failure

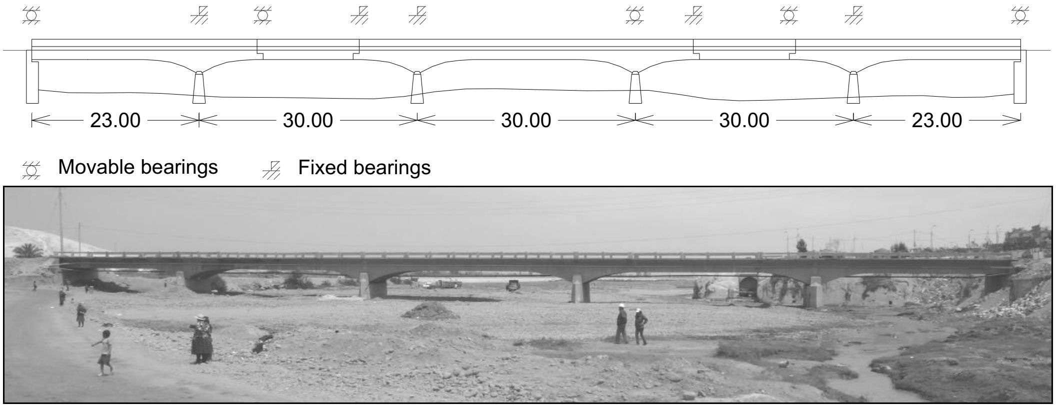

Figure 22. Layout of the Huamani bridge (downstream direction)

The bridge superstructure permanently moved upstream about 8cm. At the movable bearings on the abutment, the steel fittings separated from the concrete structure. The stoppers, on the pillar's movable support, which were supposed to restrain the transverse movement, were not found. Probably they had been completely corroded away. The lateral movement of the bridge caused damage to the concrete wings of the pillars, especially that with the movable bearing. These wings had very little steel reinforcement (Figure 23 and 24).

Overall the bridge performed very well. Immediately after the earthquake, traffic continued, but was restrained to one truck at a time. To improve the traffic conditions, a temporary passage along the riverbed was later prepared and was still in use while the bridge was been repaired when we passed this location on several occasions from September 8 to 18.

Landslides and rock falls were observed in roads penetrating from the coastline to the mountain side. These were swiftly cleaned and traffic was restored relatively fast. Some bridges along these roads suffered minor damage such as settlement of the abutment backfill. In one case, at the Tsej Tji Bridge along Los Libertadores Highway, damage due to the impact of a rock on the substructure was observed.

Figure 23.Failed wing with poor reinforcement (pillar with movable bearing)

Figure 24.Failed wing with poor reinforcement (pillar with movable bearing)

RESPONSE

Disaster response is a function that belongs to the National Institute of Civil Defense and the local governments. Therefore, coordination among these entities is fundamental for a successful response. Incidentally, in January 2007, the authorities at local governments changed and therefore, most of them, except for those who were re-elected, had less than eight months in office. In addition, there are few disaster management career officials at the local governments. These two factors hindered the response capacity of local governments. In this section, some of the disaster response aspects will be discussed.

Debris removal

Debris removal proceeded swiftly with heavy machinery in Pisco immediately after the earthquake. After this, there was a period in which removal was carried out by crews, approximately 1,800 people, hired by the Ministry of the Presidency in the framework of the Building Peru Program. No heavy machinery was observed in Pisco by our team in this period. Eventually, almost a month after the earthquake, heavy machinery re-started cleaning Pisco. Residents who had their houses collapsed could request assistance from the municipality to remove the debris from their lots by submitting a form. In addition, many people were cleaning their properties by themselves. This was observed by the reconnaissance team especially at Tambo de Mora and Guadalupe, Ica. It is worth noting that the cleaning progressed faster due to self support in towns where tourism is the main economic activity, such as Lunahuana, in the region of Lima.

Temporary facilities

A few temporary houses were observed in downtown Pisco (Figure 25). To be eligible for this, the beneficiary should first clean his/her lot from debris. Many people, who could not benefit from these facilities, built their own temporary houses with the material they could recover from their collapse house roofs, mainly straw mats. At some visited locations housing requirements were mostly covered by tents. At schools, such as the San Luis Gonzaga High School in Ica, temporary classrooms were being installed while the team was surveying. Also, temporary health centers were installed in Pisco (Figure 26).

Refugee camps

Approximately 90 camps were operating as of October 2007. According to a Health Ministry Situational Report [6], in most of the camps, there were insufficient tents for the sheltered population. Other problems include insufficient temporary toilets and cylinders for solid waste collection, which just cover approximately 20% of the demand. Water was distributed by EMAPISCO in cistern trucks and food was distributed by PRONAA and SODEXHO (a private company) and when necessary cooked in the camp.

Figure 25. Wooden temporary house

Figure 26. Temporary health center in Pisco (Ica) (courtesy of Ms. Shizuko Matsuzaki)

CONCLUDING REMARKS

Although building codes for adobe, masonry, reinforced concrete as well as a recently revised seismic design code are enacted in Peru, in practice most of the houses do not comply with them. Therefore, it is important to improve the code enforcement system at the design and construction levels. Although such a system should, ideally, be also applicable for house construction, in practice, it will take time for this to become a reality in Peru because self construction is widespread there. In order to improve the quality of the housing stock, programs to train masons may be essential to overcome the current situation.

Retrofitting of seismic weak structures is necessary for public and private buildings. Emphasizing the retrofitting of structures that have a special significance to the population, for instance churches, can become useful opportunities to create disaster awareness among the population. Pilot projects to introduce to the population earthquake resistant construction techniques are also good opportunities to raise their awareness and educate them.

Inadequate land use is also an issue. Vulnerable areas in many cities have been already identified by programs carried out by the Civil Defense Institute. Hazardous locations at the affected areas coincide very well with the most damaged locations. However, putting these findings into practice still takes too long time.

ACKNOWLEDGEMENTS

All the members of the reconnaissance team would like to express their gratitude to the many people, who in spite of their busy schedule in the aftermath of the disaster, spared time and provided us with all available materials, advise, and information at their disposal to help us with our survey. Special thanks to the people of CISMID with whom we carried out a 2-day microtremor measurement campaign. We would also like to express hereby our sincere sympathy to the people affected by this devastating earthquake.

REFERENCES

[1] National Institute of Civil Defense, Emergency Report No. 344 24/10/2007 / COEN-SINADECI / 18:00 (Report No. 62) and annexes,

[2] Tavera H, Bernal I, Salas H. The August 15, 2007, Pisco earthquake (7.9Mw). Department of Ica – Peru. Preliminary Report. Lima-Peru. August, 2007. http://khatati.igp.gob.pe/Webs/cns06/reportes/2007/sism_150807.pdf. (in Spanish)

[3] http://www.globalcmt.org/CMTsearch.html

[4] Chen Ji (UCSB), and Yuehua Zeng (NEIC), Preliminary Result of the Aug 15, 2007 Mw 8.0 Coast of Central Peru Earthquake, http://earthquake.usgs.gov/eqcenter/eqinthenews/2007/us2007gbcv/finite_fault.php

[5] INGEMMET: Geological map, quadrangle 27k, 1999

[6] ftp://ftp2.minsa.gob.pe/descargas/Especiales/2007/unidos/ as retrieved on October 22nd, 2007.