Learning from Earthquakes

The Nazca, Peru, Earthquake of November 12, 1996

The information in this article is a combination of reports from Professor Juan Bariola, who is in the Department of Engineering at the Catholic University of Peru in Lima, Peru, and Professor Julio Kuroiwa from the University of National Engineering also in Lima. A two-day trip by Professor Bariola to the Ica area was funded by the Catholic University of Peru and GTZ, Germany.

Introduction

On November 12, 1996, at 11:59 a.m. local time, an earthquake of magnitude 7.3 with epicenter in the Pacific ocean struck Peru's mid-southern region. The quake measured an intensity VII on the Modified Mercalli (MM) scale over an affected area of about 5000 km². In smaller areas with unfavorable soil conditions the intensity reached VIII MM.

The Nazca region is very active seismically because of the interaction of the Nazca and South American plates. High-intensity earthquakes of IX MM previously affected the area in 1664, 1716, 1913, and 1942. The magnitude of the 1942 earthquake was 8.2. It is estimated that the 1913 earthquake also had a magnitude of about 8.0. All of these previous earthquakes devastated the region surrounding Nazca.

The November 1996 earthquake caused extensive damage to heavy and weak adobe construction and a dozen reinforced concrete school buildings. Some lifelines were also affected. A damage report released by Peru's Civil Defense Program indicated 15 deaths, which did not include two miners trapped underground; 585 injured; 66,420 people affected; and 3,868 destroyed dwellings. Damaged to different degrees were 9,691 homes, 76 schools, and 7 health centers.

The city of Nazca, located 444 km south from Lima via the Pan American Highway, was the most severely damaged city. According to the 1993 census, this urban area is inhabited by 28,192 people.

An investigation completed in April 1996 on the microzonation of Nazca for land use planning for disaster mitigation, and on seismic risk assessment, provided very valuable information for the post-seismic survey. This study was Pedro Huiman’s professional thesis of civil engineering at CISMID, National University of Engineering Lima-Peru. It was a part of the Peru National Program for Disaster Mitigation related to the International Decade of Natural Disaster Reduction (IDNDR).

Geographic Setting

Nazca and the most affected areas are situated on an extensive plain located between the coastal mountain range and the Western Andes range on the slopes of the latter. The urban areas of Nazca are located from 560 to 595 m above sea level. The soil in general consists of 0.80 to 3 m of clay overlying a thick conglomerate stratum.

The city is crossed by two rivers. The northernmost one-third of the city is the flood area of the river Aja, located at its northern edge. The ground water level in that area varies from about 1 m below ground during the rainy season in its upper basin from January to March, to about 5-6 m below ground in December. At the time of the earthquake it is estimated that the ground water was at a depth of 4.5 m. The microzonation investigation indicates that Nazca should densify its population in the southern two-thirds of its present location.

Damage to Structures

The geographic distribution of damage to adobe buildings followed the pattern of past events: light damage was experienced by buildings located on rock and compact dry soils and heavy damage was seen in buildings located on soft, humid soils as well as uncompacted slopes. The roofs on adobe buildings are generally light and non-rigid so the maximum horizontal amplitude occurs at the upper part of the walls, which vibrate like a free border. The typical mode of failure results when flexure cracks propagate downward at the corners, leaving the walls in a cantilever position, and the walls then collapse. No damage was observed in one- or two-story well-built adobe or masonry dwellings.

Damage to concrete/masonry buildings occurred in the departments of Ica, Arequipa, and Ayacucho y Huancavelica, in Southern Peru. In Nazca, which is located in the province of Ica, the Municipality, the Stadium, and many school buildings were affected. In the Nazca Stadium, a cantilever roof collapsed and beam-column joints of the sup-
porting frame were completely cracked. The Municipality showed signs of distress that caused wide cracks in infilled masonry walls.

Most of the engineered buildings in the area are schools built with concrete frames in one direction and bearing masonry walls in the other direction. Seven schools were visited in Palpa and Nazca, both cities at hypocentral distances of around 120 km. In Nazca, site intensity seemed to have varied appreciably, since similar school buildings exhibited different amounts of damage.

There were no strong motion instruments in the severely shaken area. The general opinion in the area, however, was that the ground predominantly moved in the horizontal direction at low frequencies. Ground motion in the coast of the Andean region is usually characterized by large spectral displacements in the short period range as compared to other tectonic settings. This fact is not recognized in seismic codes. Therefore, many low-rise buildings may lack adequate stiffness and suffer excessive damage.

Most school buildings were either constructed about 20 years ago or were built rather recently and are only a few months old. For all schools, this was the first strong shake, since the last earthquake in the area occurred in 1942.

School buildings are made of reinforced concrete frames with either infill walls or load-bearing walls. Floors and roofs are one-way concrete slabs made of joists and hollow brick. In all school buildings, masonry walls make them quite stiff in one direction while somewhat flexible

Figure 1 - Layout of "Torre" school.

in the other direction, in which lateral forces are taken only by concrete frames.

A new type of school building, named "Torre" (see Figure 1), is a 3-story structure, which in plan is composed of a rectangular area, an octagonal area, and a stair shaft all joined by a common slab floor. Its structure is a re-inforced concrete space frame plus bearing masonry walls in one direction. Infilled hollow-brick

Figure 2 - Side-view of Fermin del Castillo school in Vista Alegre.
walls are present in the other direction. The Torre-type school generally showed acceptable behavior, except at the Fermin del Castillo school in Vista Alegre where apparently local site effects caused large intensities (see Figure 2). The response in the direction parallel to load-bearing walls was quite good, since wall stiffness limited displacements. In the orthogonal direction, flexibility of frames caused extensive damage of stucco, windows, masonry infills, and loss of concrete cover on some columns. Even though the structure is in repairable condition, its behavior could have been improved largely by augmenting the stiffness of the frames.

The most common school building, referred to as the "780" (see Figure 3), is a two-story concrete frame structure with infill masonry. On the corridor side, partial infills in the longitudinal direction create short columns. This plan is still used in new buildings with some differences: (1) transverse infilled walls have changed to load-bearing walls; (2) One-inch joints separate longitudinal infills and columns. The intent of this is to avoid the short column effect. Unfortunately, in practice, joints were ineffective (see Figure 4).

Generally, the 780 building showed poor behavior because of its lack of stiffness, the short column effect, and poor construction quality. The computed natural period of vibration, assuming that the columns are effectively separated from the infill walls in the longitudinal direction, is equal to 0.45 seconds, which is quite large for a 2-story structure. Estimated drifts for a soft-site ground motion calibrated at 0.4 g are in the 2%-3% range (Bariola, 1995). In some cases, insufficient or the complete absence of ties was observed.

In some of the older school buildings, masonry walls were built at both sides of columns in the longitudinal direction, eliminating short columns and increasing the longitudinal stiffness. Two buildings of this type (see Figure 5) did not show any damage.

**Damage to Lifelines and Transportation Systems**

An elevated water tank in Nazca, with a volume of 450 m³, suffered flexure and shear cracks in its beams near the joints to the supporting columns. The filtering galleries, built by the Nazca people more than 1,000 years ago, suffered light damage. This system still provides water to important portions of the city. This system, together with the famous gigantic Nazca Lines, which are as old as the former, are two popular tourist attractions.

The reinforced concrete bridge over the Yauca river, located 567 km south of Lima, suffered shear cracks on the beam of the frame supporting the bridge in the middle of the river. The presence of classical "volcanos" and important cracks on the river bed indicate that soil liquefaction

---

**Figure 3 - Layout of "780" School.**
occurred. This also happened at the mouths of some rivers of the macroseismic area.

The Pan American highway, which runs north to south, was in service except for heavy trucks on the Yauca river bridge. However, the roads climbing to the Western Andes mountain range were interrupted at many locations, hindering relief activities.

Mine tails containing cyanide used for gold exploitation contaminated the Yauca river, so water for human consumption was being transported by trucks.

Reconstruction Efforts

It had been recommended that the detailed damage survey and reconstruction work be carried out with the participation of universities located from Lima to Arequipa, 1,000 km apart, with Nazca almost at the center.

In this earthquake, nature repeated lessons left by past earthquakes. At the time of the occurrence of the Nazca earthquake, a HA/Geneva-Peru Civil Defense Program Disaster Mitigation manual for a "Train the Trainer" program was ready for printing. Approximately 55,000 of these manuals are to be sent to every school in the country for training primary school teachers. This is also a part of Peru's Program for the IDNDR.

Conclusions

The Nazca earthquake evidenced deficiencies in seismic codes, design, and construction. Where lateral forces were taken by concrete frames, with a lack of stiffness, damage was observed. Meanwhile, where lateral forces were resisted by stiff masonry walls, the behavior was excellent. The earthquake also showed that site intensity varied appreciably in the city of Nazca. Unfortunately, as has occurred in previous earthquakes, school buildings suffered serious damage.

References


The publication and distribution of this report were funded by National Science Foundation Grant #CSM-9526408 as part of EERI's Learning From Earthquakes project.