Learning from Earthquakes

The February 21, 1996 Chimbote Tsunamis in Peru

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On February 21, 1996, at 12:51 GMT (7:51 local time), a large earthquake struck at S 9.620°, W 79.568°, approximately 120 km off the northern coast of Peru. Estimates of magnitude included M_W = 7.5 (Harvard) and M_W = 7.3 (USGS). The available data suggest a low angle thrust subducting the Nazca Plate beneath the South American Plate with complex and relatively slow rupture characteristics. Aftershocks of M_W = 5.4 or lower occurred in the area bracketed by the latitude S 9.3° to 10.2° and the longitude W 80.0° to 79.6°. The aftershock pattern ranged from 120 to 180 km offshore near the Peru-Chile trench and appeared to parallel the trench and the Peruvian coastline. Tsunamis resulting from the quake impacted the Peruvian coast.

According to the Institute for National Civil Defense in Peru, the damage and casualties are as follows:

- Fatalities: 12
- Gravely Injured: 1
- Injured: 54
- Requiring Assistance: 275 (85 compensated for loss of crops)
- Houses Affected: 37 (15 destroyed)
- Boats Damaged: 25 (2 destroyed)

Some of the fatalities were from line fisherman who were caught on the rocks by the tsunamis. Additional fatalities occurred to people who were gathering wood for fuel from the mouth of the Santa River and to two people looking for gold at Campo Santa. In the town of Coishco (approximately 10 km north of Chimbote), a 30-m long brick wall framed by reinforced concrete columns was destroyed by the tsunami impact, and similar destruction was also observed at the port of Culebras, approximately 15 km north of Huarmey (Figure 1).

Tide-gauge records for the day of the tsunamis were obtained at the ports of Salaverry and Chimbote. The record at Chimbote shows the arrival of the wave shortly after 9:00 local time on February 21. The gauge indicator rose immediately and then malfunctioned for half an hour. The tide gauge at the port of Salaverry (approximately 20 km south of Huanchaco) shows a sharp upward spike of 0.75 m at approximately 9:20 a.m. followed by a downward excursion of at least 0.65 m. It is noted that due to high swell conditions, both ports were closed when the tsunamis attacked on February 21

Persons interviewed generally reported that the shaking due to the earthquake was mild (estimated intensity II to III in the modified Mercalli intensity scale). Near the vicinity of Chimbote in the middle of the tsunami-affected area, the shaking was not even noticed by everyone. In the northernmost part of the survey area, we could find virtually no one who noticed the temblor.

Those interviewed generally reported the appearance of the wave as black with no indications of breaking. Occasionally a hissing sound associated with the wave was mentioned. Many people recalled either two or three waves with the second being the largest.

The coast of Peru in this area is arid with areas of wind-blown sand. The beaches are of two main types: the coastal area north

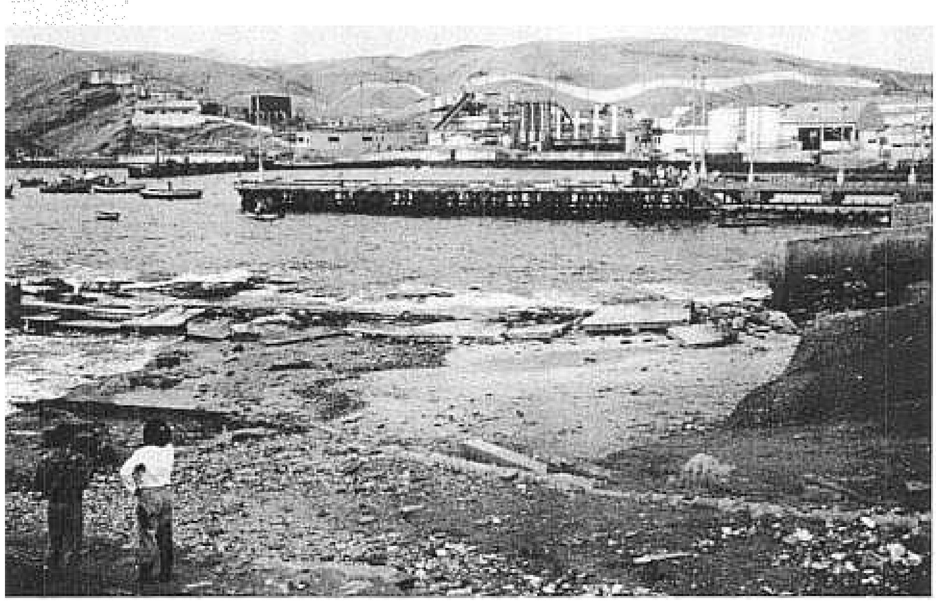

Figure 1 - *Destruction of the wall at the Port of Culebras. The maximum runup of more than 5 m was measured at the nearby ravine.*

from Chimbote has wide plane accretionary beaches with very flat slopes, and the area south from Chimbote has, in general, sheltered curved beaches anchored by rocky outcrops. The curved beaches usually have somewhat steeper slopes. Since there is very little vegetation outside of irrigated areas near the rivers, traditional evidence of tsunami passage such as marks on trees were usually absent. Runup heights were often based primarily on the evidence of debris lines which in this region can be easily erased by the blowing sand.

Measured tsunami runup heights generally varied between 2 and 3 m with the maximum 4.4 m measured at Playa Dorada (approximately 15 km south of Chimbote), on a peninsula directly exposed to the tsunami source. There are several tsunami splash marks higher than 4.4 m in areas where there was some local topography to focus the tsunami. (The term "runup" refers to the vertical distance between the elevation of maximum tsunami penetration and the elevation of the shoreline at the time of tsunami attack.) The range of run-up heights is fairly uniformly distributed in approximately 240 km of coastline from Huanchaco to Huarmey. This distance of the tsunami-affected coastal regions is considered to be long in comparison to the area of aftershocks (approximately 100 km by 60 km).

Although runup heights were not extremely high, inundation distances were often quite large because of the flat beach slopes. Several of the inundation distances were well over 200 m. In one case the tsunami inundated an entire isthmus (near Chimbote), approaching from both sides to cover a distance of 1500 m and carrying fishing boats 300 m onshore (Figure 2). In Campo Santa, tsunamis evidently penetrated onto a very flat sandy beach to a distance of more than 450 m. Very long penetration distance on mild-slope beaches implies that the tsunami period was long.

Areas of sand deposition were observed throughout the affected region. The greatest deposition occurred near the outlet of rivers where there was sand available for transport and where the beaches tended to be flat. Deposits were also more easily observed in these areas because the river activity had developed a soil surface. This allowed the deposits to be easily distinguished from the underlying layers. Tsunami deposits were noted to have buried the bases of plants that had been growing on the former (pre-tsunami) soil surface. The sand appeared to be normally graded with the coarsest grains at the base and no apparent indications of internal stratigraphy. We also observed several areas of river bank erosion evidently caused by the tsunami runup and drawdown along the rivers.

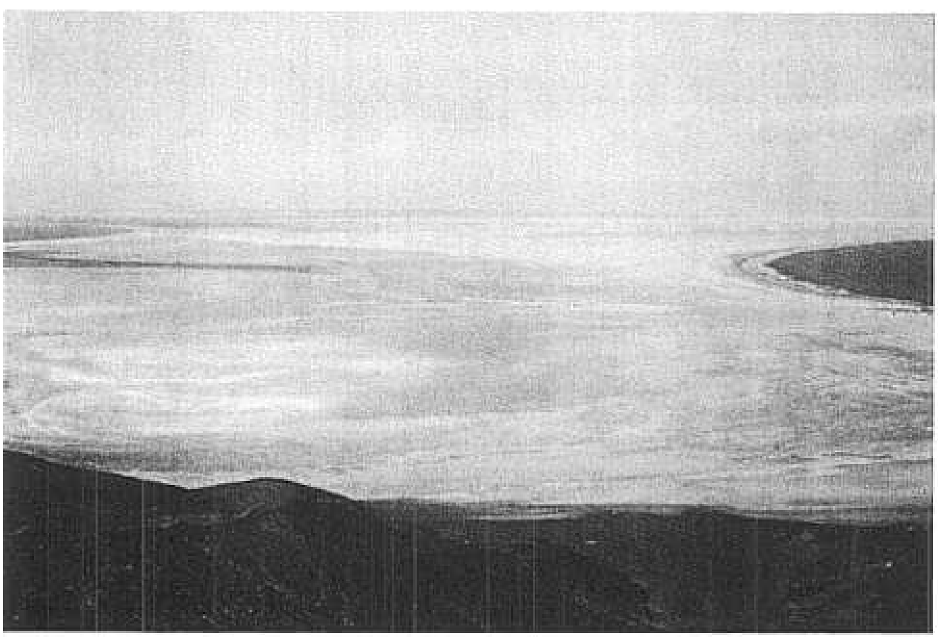

Figure 2 *- A scene of the 1,500 km wide isthmus between Chimbote and Samanco Bays. Several boats, that appear as small dots in the middle of the photo, were carried 300 m from the beach by tsunamis. The tsunami inundated the entire isthmus connecting Chimbote and Samanco Bays.*

The reconnaissance survey of the tsunami effects reported in this article was conducted between March 15 and March 22, 1996. The survey participants were Boyd Benson (University of British Columbia, Canada), Jody Bourgeois (University of Washington, USA), Guillermo Hasembank (Directorate of Hydrography and Navigation, Peru), Julio Kuroiwa (National University of Engineering, Peru), Jim Lander (University of Colorado, USA), Edmundo Norabuena (Geophysical Institute of Peru, Peru), Jorge Paz (Directorate of Hydrography and Navigation, Peru), Catherine Petroff (University of Washington, USA), Costas Synolakis (University of Southern California, USA), Vasily Titov (University of Southern California, USA), and Harry Yeh (University of Washington, USA). The survey was supported by the National Science Foundation.

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