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PRELIMINARY REPORT - PERU EARTHQUAKE OF 31ST MAY, 1970

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INTRODUCTION

At 3:23:28 p.m. local time on Sunday, 31st May, 1970, an earthquake with a magnitude of approximately 7.7 on the Richter scale occurred with its epicenter located about 25 miles off shore at Chimbote, Peru, as shown in Fig. 1. The epicenter was located 9.4°S, 78.9°W and the focal depth has been reported to be 25 km. In terms of loss of life and property damage, this earthquake was the most destructive known to have occurred in the Southern hemisphere. The toll of human lives will undoubtedly never be known. Reports varied widely, at times by as much as a factor two or three. An approximation could be as follows: Yungay and Ranrahirca 20,000 dead, Huaraz 12,000 dead and all other areas 5,000 dead. Reports have placed the death toll as high as 70,000 dead. The number of collapsed adobe dwellings must surely have exceeded 100,000. Apparently the earth displacement was primarily lateral and not vertical because of the lack of any significant tsunamis associated with the earthquake. A difference in tidal elevation of 3.7 feet was recorded over a period of approximately 45 minutes in Chimbote.

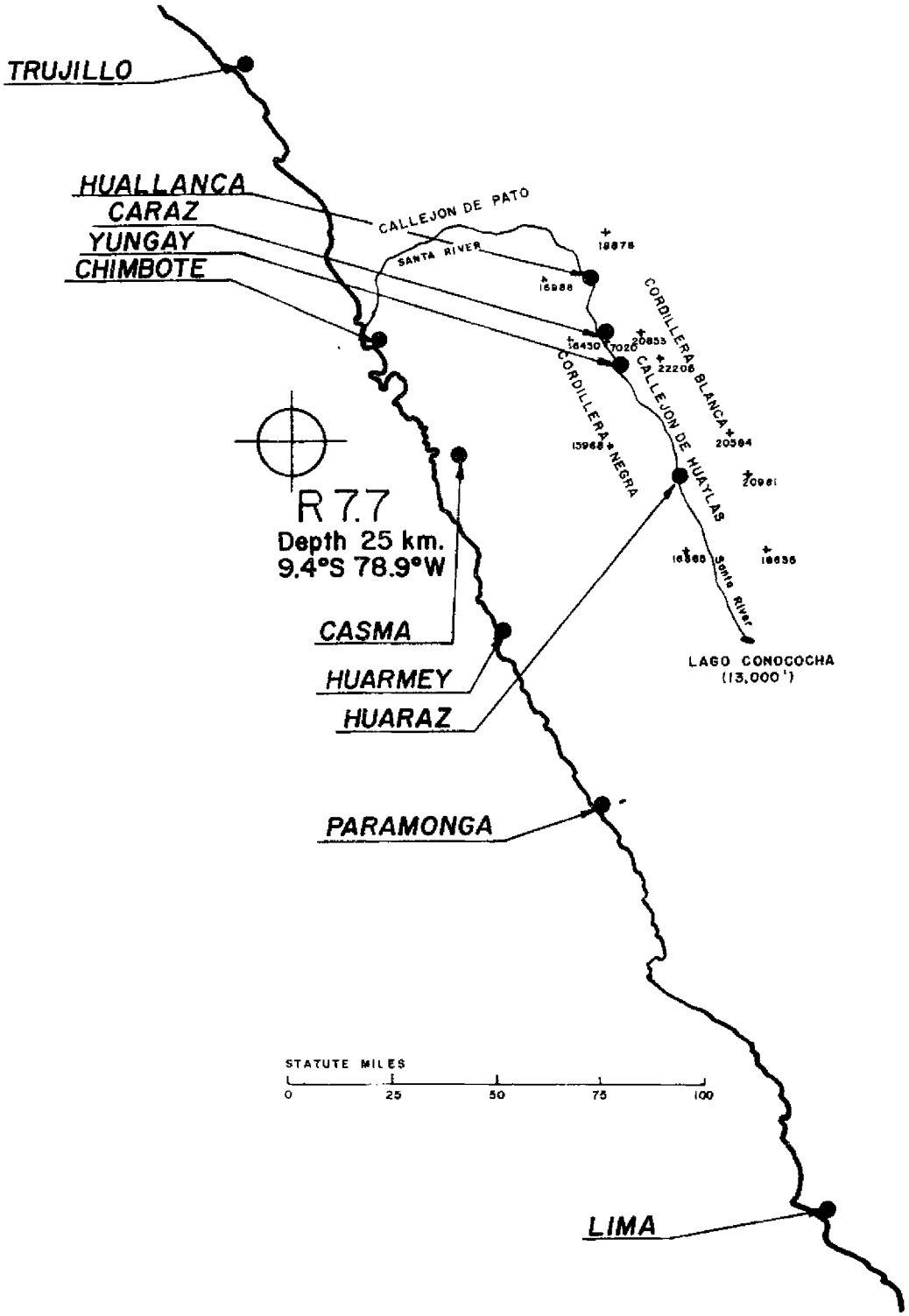
The earthquake had a devastating effect on the coastal cities and towns of Chimbote, Casma, and Huarmey. Trujillo suffered damage to a lesser degree, and at Paramonga slight damage was noticed at the Complejo Industrial (W.R. Grace Plant) and its adjoining housing areas.

The devastation in the above areas was due almost entirely to the collapse of adobe dwellings. Other failures occurred in reinforced concrete schools and commercial buildings. A two-story reinforced concrete convent (with brick filler walls) completely collapsed in Chimbote.

Collapsed dwellings were found from Trujillo to Agro Pecuaria Santa Rosa just south of Paramonga, a distance of approximately 220 miles.

Perhaps it should be noted that some very minor damage was recorded in Lima and Chiclayo. The two cities are approximately 450 miles apart.

The three-span bridge at Casma (35 miles from epicenter) was thrown completely off its rollers, while an identical bridge between Trujillo and Chimbote at Viru (65 miles from epicenter) was undamaged. Ground motion was very evident at the Casma Bridge.



Showing Location of Epicenter

The Centro de Salud (hospital) at Huarmey was only slightly damaged, while the identical design at Casma was near total collapse.

The Callejon de Huaylas is a beautiful valley situated between two ranges of the Andes known as the Cordillera Negra and Cordillera Blanca through which the Santa River flows. The Cordillera Blanca on the East side has peaks that range between 20,000 and 22,000 feet. The Cordillera Negra is about 5000 feet lower. The valley slopes downward to the North, Huaraz being at about 8700 feet and Caraz at about 7500 feet in elevation. The distance between Recuay at the South and Huallanca at the North is approximately 85 miles. Most of the communities of this valley were founded on an alluvial terrace formed by the Santa River.

SOILS AND GEOLOGIC EFFECTS

Introduction

The area affected by the earthquake includes the low-lying coastal zone and the highest mountains in Peru. In some areas the foothills of the mountains reach to the coastline. The mountains reach an altitude of approximately 15,000 feet within 50 miles of the coastline and an altitude of up to approximately 22,000 feet approximately 65 miles from the coastline. The entire area between the coast and the mountains is barren with essentially no vegetation except in the river valleys leading from the mountains to the coast. It is in these river valleys that practically all of the villages and towns are located because of the lack of water away from the river valleys. In the coastal zone there are many sand dunes and areas covered with windblown sand which reach up into the rock foothills along the coast. Except for the sand cover on some parts of the foothills, the surface consists of fractured rock without any soil cover.

Many of the rivers carry a large load of solids from the mountains and as a result the river valleys contain a large amount of alluvial material at the lower elevations. Generally, the water table is high in these alluvial areas. This is particularly true in the areas of Casma and Chimbote.

In the mountains in Callejon de Huaylas, which runs approximately north and south, there are numerous side valleys and canyons reaching into the high mountains on each side of the valley. Streams and rivers flowing from these feed into the Santa River which runs north in Callejon de Huaylas. At the north end of the valley the Santa River enters Canyon del Pato and swings westerly, reaching the ocean just north of Chimbote.

The towns in Callejon de Huaylas are located along the Santa River and are generally built on an alluvial terrace. Some of the deposits have been carried down the side valleys, from the mountains to the east as mud and debris flow, depositing large amounts of materials suddenly and causing severe damage or total destruction to any towns or villages in their path.

Canyon del Pato is a very steep-sided gorge and is nearly inaccessible. A railroad has been built through it from Chimbote to the north end of Callejon de Huaylas but an automobile road had not been constructed through it.

It is not the intent to describe the geology of the area herein in detail. Information on the kinds of rock and their history are available elsewhere and more detailed geologic reports pertaining to this earthquake will be prepared by others.

Soil Conditions

The soils in the lower river valleys and along the coast generally appeared to be silty fine sands. At the paper plant at Parmonga it was reported that such soils extended to a depth of about 10 feet, at which depth gravelly deposits were encountered. At Chimbote, information from some soil borings on land indicated that the silty sand was very loose for a depth of about 3 feet and was only slightly denser to a depth of 15 feet, the depth of the borings. Borings drilled in connection with the design of the ore handling wharf at Chimbote indicated that on the order of 3 to 15 feet of black mud was present on the bay bottom. This was underlain by loose silty sand extending 5 to 15 feet deeper. A very dense sand deposit was encountered below the silty sand.

The area on which most of Chimbote is built is low-lying. It appears that the surface soils are probably windblown fine sands which may overlie alluvial sands over a large part of the city. In the southern part of the city marshy areas are still present in areas which have not been built upon. Reeds and other water-oriented plants grow profusely in the marsh areas. It is probable that windblown sands covered such marshy areas in some parts of Chimbote before it was built up.

In the area of the new addition to the steel plant at Chimbote, the ground surface is somewhat higher than in the downtown area of Chimbote. The soils exposed in a cut slope in the yard area indicated that the soils are basically a silty fine sand which contains many rock fragments apparently derived from talus material from the nearby hills. Interspersed in this were sand lenses which apparently were of windblown origin.

Geologic Effects

The most spectacular result of the earthquake was the debris avalanche which originated on Mt. Huascaran and destroyed Yungay and Ranrahirca. In addition, the shaking caused slides and dislodged rocks on both natural and cut slopes. The roads leading into Callejon de Huaylas were temporarily closed because of slides. In Canyon del Pato the railroad line was destroyed in part by rock slides from the steep canyon walls.

At Chimbote the area adjacent to the marsh and probably the marsh area itself settled as a result of the shaking. No elevation measurements were available at the time of inspection of this area, but the water which covered previously dry areas indicated that some subsidence must have occurred. It appeared that the water which inundated the low-lying area resulted from water which was expelled because of densification of the soil due to the shaking.

Along the shoreline at Chimbote, movement of the soils towards the ocean occurred. The amount readily visible was on the order of 4 to 6 inches, varying somewhat along the length of the waterfront. While the movement appeared to be basically horizontal, some vertical movement occurred as is evidenced by the settlement of the patio area at the Chimu Hotel with respect to the hotel itself. This amounted to approximately 1-1/2 inches at the hotel. Similar movements were reported to have occurred in other coastal areas near the epicenter.

Just north of Chimbote a fishmeal plant built at the base of a rock hill was practically destroyed by a rock slide from the hill. Farther north, on the delta of the Santa River, movements occurred on the side slopes of a creek or irrigation channel.

Where the Pan American Highway traverses the marsh area in Chimbote, considerable movements of the roadway fill occurred. Reportedly, the fill split down the middle, leaving an opening of approximately 3 feet width. With this type of movement and the failure of the slope at the edge of the roadway, the raod was not usable until repairs could be made. Near Casma, where the road passes over the alluvial river deposits, there were indications of subsidence of the fill because of the bumps in the roadway at culvert and small bridge structures. Reportedly, water spouted to a height of about 3 feet in cracks in the paving at some points and water flowed along the side of the road as a stream for several hours after the shaking had stopped. The road had suffered some damage in this area but was not completely unusable. Where the road runs along the base of a rock hill, rocks fell from the hill and blocked the road. At the Casma River bridge subsidence of the approach fills at each end of the bridge occurred and the abutments moved towards the

river. The ground surface upstream of the bridge approximately 50 feet from the river was cracked and it appeared that sand had been carried up from below the surface soils by water from this crack.

At the water supply facilities for Lima, at Atarjea on the Rimac River east of Lima, loose soil which had been placed on the outside slope of a reservoir embankment showed signs of creeping down the slope. The total amount of movement was on the order of 2 to 3 inches.

TYPES OF CONSTRUCTION

By far the most common form of construction is adobe, which is used for most of the houses and small structures throughout the region. Many two-story and a few three-story adobe buildings exist, some of them quite large. Some roofs are mud plastered over cane on timber joists, some are tile-formed concrete joists and slabs, and some are tile or corrugated transite on wood pole rafters. Bearing wall brick buildings are frequently used for shops, apartments and residences. Some have bond beams and some do not. Reinforced concrete framed structures with brick filler walls are used for many smaller industrial structures, shops office buildings, apartments and schools. The four or five major industrial buildings in the earthquake region are traditional braced steel-framed buildings with steel trusses and purlins and corrugated iron or asbestos cement (transite) roofs.

Quincha construction is frequently employed for residences in the coastal region. A quincha wall consists of vertical poles spaced a meter or two apart, usually braced at the bottom in the plane of the wall, with a horizontal cap pole tied to the vertical poles at the top. Two or three equally spaced horizontal poles or canes are tied to the verticals to complete the basic frame work. Then canes are placed vertically, tightly spaced and woven between the horizontals in a basket weave. Finally the wall is plastered with mud on both sides. The roof is usally built of wood pole joists or rafters thatched with grass or covered with corrugated iron.

Quincha construction is quite flexible compared to adobe construction and thus has the highly desirable property of flexing with the ground motion; that is, it will "roll with the punch." whereas adobe is brittle and will not tolerate much motion without cracking and falling.

In general, a few comments on the materials used for construction would be noteworthy.

(a) The mortar used in adobe construction seemed to be almost a cohesionless material in its final form.

(b) The quality of the adobe blocks appeared to be better in the inland areas as contrasted to the coastal regions.

(c) Concrete in many instances appeared to be of poor quality. This may have been the result of unclean aggregate, low cement content, and improper aggregate grading. Visual observation indicated that perhaps 750 p.s.i. to 1500 p.s.i. was the usual compressive strengths obtained, with perhaps 2000 p.s.i. in some of the schools.

(d) The slow rate of construction combined with the salt atmosphere of the coastal regions permitted, the long time exposure of the reinforcing to accumulate considerable rust scale before pouring of concrete. This scale, in most places noted, had not been removed and bond was indeed questionable.

EARTHQUAKE INTENSITY

The Modified Mercalli scale of earthquake intensity is inexact and somewhat subjective, and an observer may get different results by selecting the effects he wishes to observe. Attempting to appraise the intensity on the basis of average effects in the locations named, and taking into account the quality of construction, we find the Modified Mercalli Intensities to be:

CASMA	VIII
CHIMBOTE	VIII
HUARAZ	VII-VIII
HUARMEY	VII
TRUJILLO	VI-VII
HUALLANCA	VI

STRUCTURAL DAMAGE AT VARIOUS LOCATIONS

COASTAL REGION

Along the coastal region of Peru, significant structural damage was found from Agro Pecuaria Santa Rosa to Trujillo, a distance of some 220 miles. Casma, about 35 miles from the epicenter, and Chimbote, about 25 miles from the epicenter and located near the middle of this coastal strip, were the most severely damaged coastal cities. The following are comments concerning selected buildings in towns along the coastal region of Peru.

Agro Pecuaria Santa Rosa:

This very small village (perhaps 30-40 dwellings) is located about 140 miles from the epicenter of the earthquake.

Although rather far removed from the epicenter, every dwelling in this village collapsed. One eyewitness told of the earth opening up and closing repeatedly with a seemingly much exaggerated description.

All dwellings were constructed of adobe bearing walls.

Paramonga:

Located about 100 miles from the epicenter, is the site of the Complejo Industrial Paramonga (W. R. Grace Plant) consisting of a sugar refinery, paper mill and chemical plant. Cane fiber from the sugar operation is used to make paper. The administration building, a two-story reinforced concrete frame building with brick filler walls, had been damaged by the previous 7.2 Richter Magnitude earthquake of October 17, 1966, located about 75 miles due west of Paramonga. The building has 16 bays - nine at one end and seven at the other, separated by an expansion joint. The end wall in the first story of the 9-bay segment failed, and column damage occurred at the second floor beams at four locations. Transverse brick walls in the first story were cracked at several locations. Damage was much less severe in the 7-bay portion of the building than in the 9-bay portion because the 7-bay portion has transverse shear walls in every bent, and the 9-bay portion has no transverse shear walls except at the end. The building could have collapsed had a little stronger or longer earthquake occurred. The end wall reinforced concrete beam and column frame showed a typical type column failure observed at several locations throughout the devestated area.

The paper mill is a large steel-framed mill building, with a corrugated transite roof supported on steel purlins and trusses and columns. Most of the exterior walls are infilled with clay brick. Damage was not severe. A few exterior wall panels high in the building fell out and an elevated tank inside the mill was thrown off its supporting platform. No settlement of foundations had been found. The paper machinery had been thrown out of alignment, and four days of production were lost while adjustments were made.

Huarmey

In this small town which is about 60 miles from the epicenter, most of the buildings were adobe and almost all of them were damaged or destroyed. In stark contrast with the adobe structures were the quincha dwellings. Some of them were damaged but they remained intact except for a few dislodged roofs or some spalled wall coatings.

The church at the plaza was totally demolished. Only the damaged reinforced concrete tower remained standing.

Of some interest is the Mercado Modelo, a market with sixteen concrete columns supporting the roof structure. Although torsion was introduced into the structure (by one side having no filler walls) it would seem by observation that this structure should have withstood the quake with considerably less damage. The structure was measured and framing plan, elevations and stress calculations have been made.

Nearby stood two old buses, without wheels, each of which had been placed on four concrete block piers about three feet off the ground. Observation would indicate that not too high a lateral acceleration was experienced in this town or the buses would have been knocked off of their supports.

The Centro de Salud (Hospital) in Huarmey was only slightly damaged. It was of identical design and construction as the one in Casma, which suffered very extensive damage.

Some slight ground motion was observed to have taken place as indicated by ground cracks.

Casma

Casma, about 35 miles from the epicenter, was almost completely destroyed. Nearly all of the buildings were adobe, and virtually all of them were either reduced to rubble or damaged far beyond repair. The bank building, a reinforced concrete frame building with brick infilled walls, had its parapet wall nearly dislodged but was otherwise intact.

The recently constructed Centro de Salud (Hospital) not yet occupied, was severely damaged.

This one-story building was constructed with reinforced concrete frames, infilled unreinforced and unanchored concrete block interior partitions and exterior walls, and typical roof reinforced concrete joist construction formed by spaced clay tile. Severe damage occurred to all masonry construction. Also critical damage occurred to many column-beam connections throughout the building. Anchored equipment was not damaged; some unanchored equipment was damaged. Glass breakage was generally found throughout the entire building. The concrete elevated water tank at the hospital site appeared to be undamaged.

Essentially all of the buildings of a large Casma School collapsed or were seriously damaged. Construction was primarily of reinforced concrete frame with masonry infilled walls. One building had roof trusses of light steel construction which had collapsed. Another had wood roof joists but had not collapsed. Most of the buildings were probably less than 10 years old.

One wing which appeared to be essentially completed, as it had not yet been painted, had the typical short column damage found throughout the stricken areas. One of the roof overhang beams of reinforced concrete sagged considerably when the brick wall crumbled opposite the bottom or the compression side of the beam.

A water tank on this school site collapsed. This was the only water tank failure observed throughout the earthquake stricken area.

A three span steel truss bridge crosses the Casma River about 2 - 3 miles south of the city of Casma. Each truss, a simple span, rests on hinged supports at one end and on segmental rollers at the other. The abutments were displaced toward midstream during the earthquake.

The concrete piers also were displaced slightly. The relative displacements between the trusses and their supports were great enough to rotate all the segmental rollers beyond their critical angle of rotation, and the rollers had fallen flat between the upper and lower bearing plates.

By contrast a seemingly identical bridge between Chimbote and Trujillo, at Viru, suffered no damage.

Chimbote

Chimbote, about 30 miles from the epicenter, is a city much larger than Casma or Huarmey because of the large fishing industry and the steel mill. Construction comparable to that found in Casma or Huarmey suffered damage of equal severity here. There was, however, larger and better commercial construction found in the downtown area.

Many of the adobe buildings were reduced to rubble and few escaped severe damage. Some districts, notably the San Pedro district, were damaged to a greater extent that Casma.

Perhaps the most earthquake engineering informative structures in Chimbote were its schools.

The Marianista "Normal" School is a two-story three year old reinforced concrete frame building with infilled, unreinforced concrete block masonry. It suffered considerable damage to the frames and masonry walls but did not collapse. The second floor and roof slab were composed of infilled clay

tile concrete joist construction. Such clay tile about 20" in length were set about 4" apart thus arranged to form concrete joists 4" wide spaced 24" and supporting a 2" slab when concrete was placed between and over the tile. Extensive damage occurred to the concrete block longitudinal and cross walls which were unreinforced and unanchored. Also, the concrete columns, all of which were about 11" wide and 23" deep, were extensively damaged at the top where they frame into the beams. Damage was greater within the first story than within the second story; however, serious damage occurred within both. Many masonry walls fell out of the frames. Such wall collapses would surely have caused deaths or serious injury to many students had the earthquake occurred during school hours.

An interesting observation can be made which typically shows greater damage to the top of the columns where the cross walls are located and less damage where no cross walls existed. A possible explanation for this behavior is primarily twofold. First, the infilled frame being stiffer than the frame without a wall initially resisted a larger load. Secondly, due to the unanchored infilled section a single concrete column of the frame had to carry all of the shear in this bent, rather than each column carrying an equal amount. It is presumed that at the time of failure of the infilled section, an impact load is applied onto the concrete frame due to the sudden fracture. Further, after the diagonal tension failure of this infilled wall one of the concrete columns must obscrb most of the load, therefore it is the opinion of this Committee that the resistance of concrete frames may be impaired by the addition of these infilled masonry walls; a phenomenon which was found in some failures that occurred throughout the entire devastated area.

Brick veneer on the end wall was dislodged generally throughout the wall. Apparently nominal anchorage was provided at the floor line.

Brother Daniel Calvo, who occupied an apartment on the second floor of this school and escaped without injury, reported seeing ground waves in the nearby school yards "going in all directions which were about 12 feet between crests and about 1 foot in height."

The San Pedro Consolidated School is an 8 or 10 year old school consisting of several wings one of which was oriented 90° to the main wings. Damage was similar in all wings and not particularly related to orientation. In all wings the short stiff columns suffered serious damage and the longer more flexible columns suffered little damage. There was, however, an exception to this. This may be explained by evidence of settlement at the end of this wing which may have increased the vertical load on the column.