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INTERNAL STUDY REPORT NO. 50

DAMAGE TO BUILDINGS IN LIMA OCTOBER 1974 EARTHQUAKE

by

Javier Pique

January 1975

Department of Civil Engineering
Massachusetts Institute of Technology
Cambridge, Massachusetts

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16. Abstract (Limit: 200 words)
On October 3, 1974, at 9:25:45 hours (EST), an earthquake of magnitude 7.8 on the Richter scale occurred. The epicenter was located 65 miles south of Lima. The total duration of shaking was two minutes and fifteen seconds. The characteristics of the shaking were "slower" than in the previous earthquakes of 1966 and 1970. In that way, this was an unusual tremor for its long duration and low predominant frequencies. Traditionally, shakings in the area have had high frequency contents. Damage to buildings in Lima and the nearby towns of Callao, La Molina and Chorrillos is evaluated. The different types of construction identified are: massive mud wall; adobe; adobe plus reinforced "quincha"; masonry construction; concrete frame; combined shear walls and frames; shear walls. The damage observations are summarized according to the different types of construction and location. The damage observations for the non-engineered buildings have been used to estimate intensity according to the MSK scale. Observations show that, on the average, engineered buildings are not necessarily stronger (in the sense of being less susceptible to damage) than those not designed for earthquake forces.

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1. INTRODUCTION

Lima is located on the Pacific Coast of Peru at a latitude of 12^{o} south and a longitude of 77^{o} west. The coastal line runs northwest and Lima is in its central region.

Seismic activity is continuous in the area. In the past eight years two other major earthquakes occurred (1966, 1970) (Ref. 4). Both had epicenters along the Peru-Chile trench between two tectonic plates, i.e., the Nazca plate to the west (the sea floor of that part of the Pacific Ocean) and the South American plate to the east. The contact zone runs parallel to the shore at 30 to 50 miles offshore.

On October 3, 1974, at 9:25:45 hours (EST), an earthquake of magnitude 7.8* on the Richter scale occurred. The epicenter was located along the plate tectonic contact zone mentioned above, 65 miles south of Lima. Fig. 1 shows the location of the epicenter and its relation to the surrounding area. Intensity has been estimated as varying from VI to VII and in some cases up to VIII in the Modified Mercalli scale.

There are two strong motion records available which have been taken by the "Instituto Geofisico del Peru" (Geophysical Institute of Peru). The total duration of shaking was two minutes and fifteen seconds. Visual estimations indicate that the peak accelerations were higher than 0.20g. It is worth noting that the frequency content of this earthquake was completely different from the ones in 1966 and 1970 (Ref. 4). The characteristics of the shaking were "slower" than in the previous earthquakes. In that way, this has been an unusual tremor for its long duration and low predominant frequencies. Traditionally, shakings in the area have had high frequency contents.

In order to evaluate damage to different types of construction in Lima, a visit was made on November 8, 1974. The idea was to identify separate areas of the city, within which the intensity of the shaking could be considered uniform. In each of these areas, performance and damage state were to be evaluated. Different types of construction were identified which were common to all of the areas. The visit took place from the 8th to the 15th of November 1974. The first days were devoted to inspecting

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*The Instituto Geofisica del Peru gives 5.6 Richter. This is the recording station in Lima. Abroad, the above figure of 7.8 is cited.

all of the city and to making the necessary contacts with people in Lima. The areas in Fig. 2 were chosen as suitable for this study. Next, several informal meetings were held with the earthquake group at UNI and other engineers. A visit was made to the Technical Division of Lima's City Hall. Finally, information regarding the strong motion records was obtained from the Instituto Geofisica del Peru, along with damage and technical data with respect to collapsed structures.

2. TYPES OF CONSTRUCTION

It is possible to identify several types of construction commonly found in downtown Lima and in surrounding areas. These kinds of construction are representative of different techniques used along the times. They are still being represented by a considerable number of buildings.

A major classification can be made based upon the fact that the building (in its most general sense) has or has not been engineered (designed) to withstand earthquake loading:

(A) Non-Engineered;

(B) Engineered.

In the first group the following types can be found:

A1) Massive Mud Wall. This is a construction made out of very thick mud walls. Thickness varies from 3 to 6 feet. It was used principally in old public buildings; i.e., churches, bullrings. The roofs in these edifications are woodwork usually covered by mud. In some cases (the oldest and less important ones), a combination of wood ribs with "joists" made out of cane covered with mud can be found. A somewhat newer type of massive wall built with adobe can be found as well. (Fig. 3)

A2) Adobe. This type is used mainly in one or two-story dwelling construction, built using common adobe (2" x 10" x 20") in either the long direction (thinner walls 10" thick) or the short direction (thicker walls 20" thick). The roof is supported by the thicker walls. The thin ones, used as partitions without direct load applied to them, are usually more likely to collapse. The roof is made with wood beams (2" x 6" @ 2') and a wooden floor.

A3) Adobe plus reinforced "quincha." This is a type that combines both the usual adobe wall as mentioned before, and a combination of wooden frame and cane covered with mud, called "quincha." The first story would usually be

adobe. The second, and in some cases the third story would be made out of this reinforced "quincha." This section consists of a wooden frame with studs spaced at 3 or 4 feet. The frames are infilled with cane and the wall thus formed is covered with mud. In some cases the lower part of the filling would be adobe up to 3 feet. In all cases the floors and roofs are wood construction (Fig. 4). Entirely "quincha" construction may be encountered in some cases, particularly in older sections of the city, or in towns in the suburban area.

A4) Masonry Construction. This category includes houses or smaller buildings built in this century. They are made out of clay brick, but no special provisions for lateral forces have been taken. Floors and roofs are made of reinforced concrete. Partitions are made of solid or hollow clay brick.

A5) Concrete Frame. Here we consider non-engineered buildings built using reinforced concrete frames. These buildings, 25 or more years old, have not been specifically designed for earthquake loading. Clay brick is used for the partitions.

In the second group of engineered construction, the following types can be identified:

B1. Masonry Construction. This type is used mostly in dwelling construction. They are made out of solid clay brick with R.C. columns in the walls. Floors are made out of reinforced concrete joists cast in place. There are usually two stories. Hollow clay brick is used for non-structural partitions in the upper floors.

B2) Concrete Frames. This construction uses cast-in-place R.C. frames designed for lateral loads in both directions, with no shear walls interconnecting the frames. Floors are made out of ribbed concrete slab cast-in-place. Hollow clay bricks are used for partitions.

B3) Combined Shear Walls and Frames. Buildings of this type have a combined structure of concrete frames plus concrete shear walls used as part of the elevator core. Hollow clay brick is used for the partitions. The floors are R.C. ribbed slabs cast-in-place.

B4) Shear Walls. There are buildings in which both vertical and lateral forces are resisted by shear walls exclusively. There are no other structural elements but R.C. walls. Interior partitions are hollow clay brick or R.C. walls. This is a rather rigid type of construction in large use for new public buildings with peculiar architectural characteristics. Fig. 5 shows a summary of the types of construction mentioned above.

3. DAMAGE ESTIMATES

3.1 Lima

All of the types of construction mentioned above are found in downtown Lima. The area is known under that same name and includes the old part of the city plus new edification in replacement of the older buildings. One accelerograph is located in the area. The record should be a fairly good representation of the shaking in this area. According to estimations at Universidad Nacional de Ingenieria, the intensity can be considered to have been VII in MMI scale.

Most engineers in Lima agree that the city has good soil conditions. This is based on the fact that the area is on a 200 to 300 ft. stratum of alluvial conglomerate, highly compacted and well-graded. At a 4' depth, the bearing capacity is estimated as being 4 Kg/cm^2 (see Ref. 1,3). The water table runs below 250 ft. Underneath this deep stratum lies the bedrock. To the east side of this area (older section) there are small mountains (800-900'), mainly of igneous rock.

In the following damage descriptions, the choice of words describing the number of buildings affected and the degree of damage follows that suggested in the MSK intensity scale (see Ref. 2).

Quantity:

Single, Few	about 5%
Some*	about 25%
Many	about 50%
Most	about 75%

Damage:

Slight damage	Grade 1
Moderate	Grade 2
Heavy	Grade 3
Destruction	Grade 4
Total damage	Grade 5

Table 1 provides a more complete description of the 5 damage states. In Fig. 2 the location of the zones studied in this report is shown. It must be noted that these areas do not necessarily correspond to their political delimitation as Lima's districts.

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*Not included in MSK definitions.

A qualitative evaluation of damage for different types of construction is as follows:

A1) Damage ranges from cracks in some walls and decorative cornices to severe wall and tower cracking with roof collapses in a few cases. Most churches present cracks either in the walls or in the tower section, sometimes in the joint between the tower and the walls. Most churches also have had damage to exterior or interior plaster decoration. Many present moderate damage to dome roofs or vaults, from fall of large pieces of plaster to widespread fall of mud and plaster from the roof. Few (actually I saw one and part of another one that was closed) had their vaults partially collapsed.

A2) Adobe has performed according to its state of preservation. It could be observed that one of the primary factors in its response was the state of preservation of the walls. Damage has been widespread anyway. Many of the structures of this kind have suffered partial collapse in the sense of gaps in the walls, separation or collapse of some walls, and loosening of cohesion of separate parts of the building. Most, if not all of them, present large cracks in corner walls and fall of plaster and interior cornices.

A3) Few structures have collapsed. Those in a poor state of preservation, whose adobe's first floor collapsed,were mainly affected. Many present slight damage such as fine cracks in plaster, fall of small pieces of plaster. In this group many had moderate damage like small cracks in walls and fall of fairly large pieces of plaster. Their behavior was slightly better than adobe construction although this time they suffered more damage than in the 1966 earthquake.

A4) Some houses present light partition cracking, but no structural damage of importance can be reported. There are three and even four-story buildings of this type that present only light cracking.

A5) In this category, there are tall buildings (6-8 stories) and rather short buildings (4 stories) with large areas (like the building of the Congress or the Palacio de Justicia Court building). With respect to the first group, many of them have partition cracking varying from very light to moderate, also some structural damage to water tanks on top. With respect to the second group of buildings, most of them have either fine cracking in the walls, or damage to cornices and other kinds of exterior decoration. Some of them have rather heavy cracks in load bearing and partition walls (Court building).

For engineered-type construction, damage is as follows:

B1) There is no evidence of structural damage to this type of construction. Some have cracking in partition walls varying from very fine cracks to moderate cracks.

B2 and B3) Most buildings in this category have partition damage, although it can be considered only moderate partition cracking. Many had their window glass broken. In a few cases overhanging portions collapsed. At least 25% of them show evidence of some light structural damage. Cracks in certain girders or columns and shear walls could be found. Damage to columns and shear walls could also be found. Damage to columns supporting water tanks on top of the buildings were also severely damaged. Some buildings present light cracks in those girders connecting shear walls from elevator or staircase cores.

B4) Some of these buildings present slight damage to partitions and a few of them have small cracks in long span concrete girders supported by shear walls (Civic Center). Since these structures are public buildings (government offices) their architectural characteristics show long spans and irregular plan distributions. Damage is very slight to these elements; however, there is evidence to substantiate this.

3.2 Callao

Callao is located ten miles west of Lima. It is the city port. Its elevation varies from 3 to 50 feet above sea level. Soil conditions are inferior to those in Lima. These are variable in the area, involving mostly silts and sands with high clay content. The water table is at 6-10 feet. Bearing capacity varies from 0.5-1.00 kg/cm^2. Intensity on the Modified Mercalli scale ranges from VII up to VIII, in estimates from Prof. Kuroiwa and others from the Universidad Nacional de Ingenieria, Lima (National University of Engineering).

A1) Can be considered to be the same as in Lima.

A2) Adobe construction in Callao has experienced heavier damage than in Lima. There are practically no buildings of this type which did not show some kind of damage. Only some of them had damage that could be considered moderate. Many had heavy damage similar to that in Lima. But there were also some which collapsed totally or to a greater extent than those suffering partial collapse in Lima.

A3) Damage to this type of construction was mainly due to collapse of the adobe first story. Most of them have heavy cracking on the walls and fall of

plaster is widespread.

A4) No structural damage. Slight cracking in non-structural partitions.

A5) There is structural damage in some buildings. About 20% show cracking in girders or columns. Light to moderate partition cracking is found in many structures. In this group a grain elevator on top of a grain silo that collapsed can be included. Cornices have fallen as well.

B1) Few houses have slight damage on partition walls. They performed well.

B2) Damage to this type of construction has been substantially stronger than in Lima with some collapsed structures. It can be summarized as follows: Few buildings have collapsed. Some have damage to structural elements and widespread partition cracking. Many show light partition damage and broken window glass.

B3) Some have moderate damage to partitions. Many show almost no damage except for light partition cracking. There are not enough buildings of this type in the area to permit generalization on their performance. There are some structures other than buildings that could be considered in this category, i.e., elevated water tanks. Their supporting structure is composed of columns and shear walls. Few of these have considerable structural damage while many of them show light to heavy partition cracking.

B4) There are no buildings representative of this type of construction in the area.

3.3 La Molina

This area is located to the west of Lima, about seven miles from the downtown area. Most of it used to be farming land although there were buildings from a small town in the old part and the agricultural university (Universidad Agraria La Molina). Developments were started a few years ago and today many sections have been populated.

About two-thirds of this area's perimeter is surrounded by mountains (900'-1300') towards the east and south. The soil conditions are variable and different than in Lima. In the zone where the buildings from the agricultural university are located, soils are silts and clays, with working loads of 0.5 kg/cm^2 (see Ref. 2). In other zones nearby there are gravels and coarse sands with silicous and acid materials, also loess sands deposited on sedimentary rock beds. Damage can be summarized as follows:

A1) There are some old churches that belonged to the former "haciendas" of the area. Their quality is not as good as those in downtown Lima. Most of them have heavily cracked walls. Damage is also heavy in the roofs, plaster and cane, and cornices have fallen off.

A2) Many (50%) of the adobe houses and construction show evidence of heavy damage and about 25% of them suffered partial or total collapse. Others have widespread cracking and loosening of the whole structure. In general, a larger proportion of houses with heavier damage existed in La Molina than in Lima or Callao for the same construction type.

A3) No structures as defined for this type can be found in the area.

A4) There are some relatively modern houses that do not seem to have received special attention for earthquake resistance. In this group there are few with structural damage, i.e., short columns broken, cracks in girders or load bearing walls. Many of these houses show slight cracking in non-structural partition walls.

A5) There are no structures of this type represented in this area. This is due to the fact that for a long time this zone did not experience new developments, having only the old structures until the agricultural university built its new campus and the surrounding area was urbanized.

With respect to engineered structural types, the situation can be summarized as follows:

B1) With the expansion of Lima to the east, many houses have been built in this zone. Of these, about 50% have only slight partition damage and a few of them do not even show any damage at all. The other 50% have some structural damage ranging from small cracks to heavy cracking in load bearing walls. For instance, there is a three-story building under construction whose structural elements are reinforced masonry walls. This structure has some deep cracks in some shear walls and cracks in other "short column" like walls.

B2) Widespread damage to this type of construction is seen everywhere around this zone. Not only in buildings at the Universidad Agraria, but other framed structures in high schools also show similar behavior. About 25% of these buildings have collapsed or suffered irreparable damage. Many of them (about 50%) have severe structural damage to diverse structural elements. Heavy partition cracking was observed as well. The rest (25%) show only partition cracking varying from very slight to moderate.

B3) Buildings as defined above for this category cannot be found in the

area. At the Universidad Agraria there is one building with one small elevator core over the second floor, but the structural system is not conceived as a frame-shear-wall combination. The shear wall and the columns were heavily damaged on this building.

B4) There are no buildings of this category in the area.

3.4 Chorrillos

There is another area where shaking was apparently different from that in downtown Lima. Chorrillos is located about ten miles south of Lima at the southern extreme of the bay. This used to be a resort town at the beginning of the century with old adobe houses. In recent times it developed toward the east. There are some mountains to the south and east of this area (200-600 ft.). Elevation is about 100 ft. Soils are silty clays in upper stratum in the northern section and dry and cracked clays in the rest. Water table varies from 60 feet up to 3 or 4 ft. in some areas (see Ref. 1). Damage in this area has been considerably higher than in Lima. Although the number of modern buildings is not very large, some types of construction are represented there. Intensity has been estimated at VIII (MMI). A survey of damage follows:

A1) Most churches have suffered considerable damage to walls and roofing. There are deep cracks in the upper part of the walls and large pieces of plaster and small sections of the ceiling have fallen.

A2) A large number of houses of this type present damage ranging from moderate to heavy. Only few of them show evidence of slight damage. As much as 30% have collapsed either partially or totally. Many have suffered heavy damage and others (25%) have suffered moderate damage.

A3) In this category damage is similar and sometimes more severe than in Lima. Many houses are heavily cracked, some show partial and also complete collapse.

A4) Many of these show slight cracking on walls. A large number of them have not suffered damage at all.

A5) There are buildings from the Military Academy in this area. Some of them show cracks in the walls and fallen cornics and decoration. There is no evidence of structural damage. Apartment buildings of the military do not show damage but there are a few cases of slight cracking.

Among the engineered buildings, damage is as follows:

B1) Many of them do not show damage. Some have slight cracking in partition walls.

B2) Damage to buildings in this category has been severe. Most of them (this includes all three observed) have severe structural damage to columns. Although buildings have not collapsed as a whole, deformations due to column failure are large.

4. FINAL COMMENTS

The damage observations are summarized in Table 2, according to the different types of construction and location. The damage observations for the non-engineered buildings have been used to estimate intensity according to the MSK scale. It must be noted that intensity on the Modified Mercalli scale tends to be greater than intensity on the MSK scale for La Molina area. This may be explained if we take into account the fact that only non-engineered buildings are considered on this estimation when using MSK. And a large part of the damage in this zone was to engineered buildings. Thus, even though the shaking could have been stronger in La Molina the intensity reflected by the MSK scale is lower than by Mercalli's. This also suggests that stronger shakings do not necessarily mean more collapses of certain type of structures unless we consider the specific characteristics of those structural types.

In terms of relative performance, the following can be concluded about damage in the region of Lima. Adobe construction presents the largest damage in terms of collapse. Masonry with concrete frames, as of type A5, presents heavy damage. Performance of engineered-type buildings has been acceptable (except for rather localized structural damage to some elements) although non-structural elements have widespread moderate damage. Masonry dwelling units show less relative damage when compared to other types of construction.

In Callao, more buildings of type B2 had structural damage than in Lima, and a few even collapsed. Clearly flexible frames suffered the most from the low frequency content of this earthquake. This fact is emphasized by the soil condition of Callao where low natural frequencies are predominant. As far as adobe construction is concerned, it can also be said that it was the type of building most affected. The difference with Lima rests on the relative proportion of houses with moderate instead of slight damage as well as on

the number of total collapsed structures. An interesting point is that several housing developments with rather rigid four-story buildings experienced almost no significant damage.

In La Molina, the shaking was estimated to be at least twice that in downtown Lima (Ref. 5) where the strong motion record was taken. The effect this difference had on adobe construction, although heavier, was not in the same proportion as this amplification ratio. But damage to engineered buildings was considerably larger than in any other area of metropolitan Lima. Most buildings (of all existing types) showed some kind of damage; at the same time, low masonry dwelling units showed the least severe damage of all. Framed structures and rigid adobe performed extremely poorly, or did not perform at all.

With respect to Chorrillos, the first impression was that of a heavily damaged area. This was because most adobe construction is grouped in one part of town. The number of collapsed adobe houses was substantially larger than anywhere else, and damage to modern buildings (although there were not many) was heavy - not to the extent of La Molina but certainly larger than in Lima and more widespread than in Callao.

A conclusion that appears time after time from these observations is that intensity of shaking does not correlate with damage to all structural types. Furthermore, on the average (see Section 3.1, for example), engineered buildings are not necessarily stronger (in the sense of being less susceptible to damage) than those not designed for earthquake forces.

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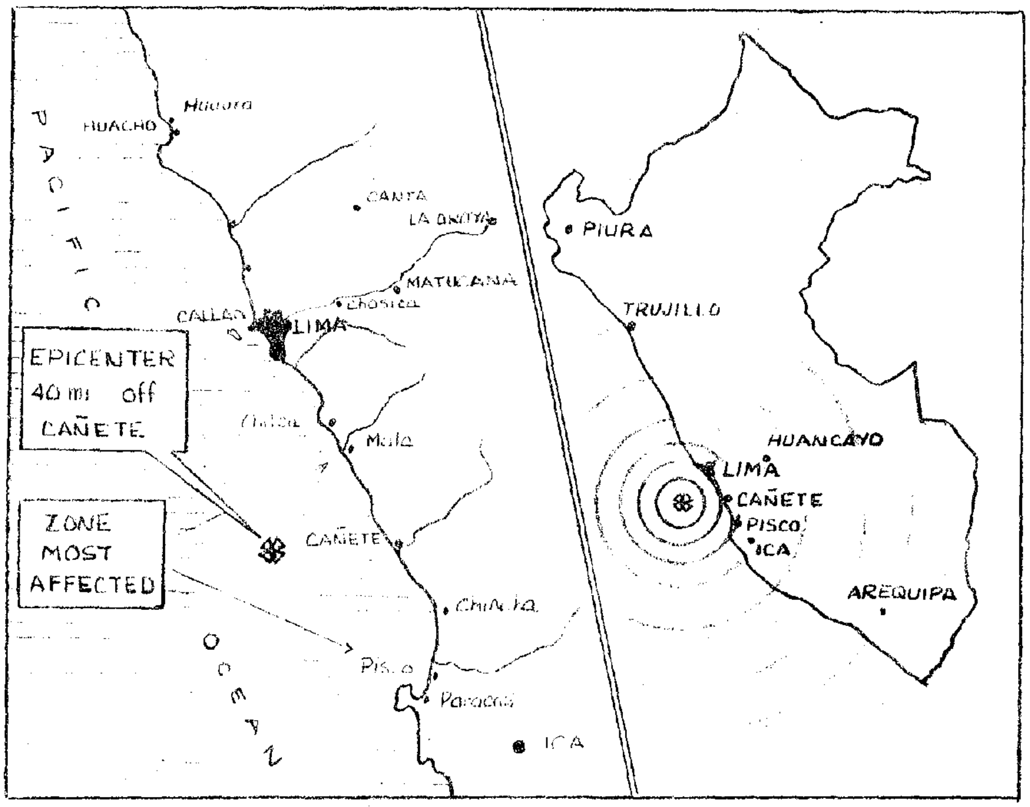


Fig. 1.- Epicenter Earthquake Oct. 3. 1974

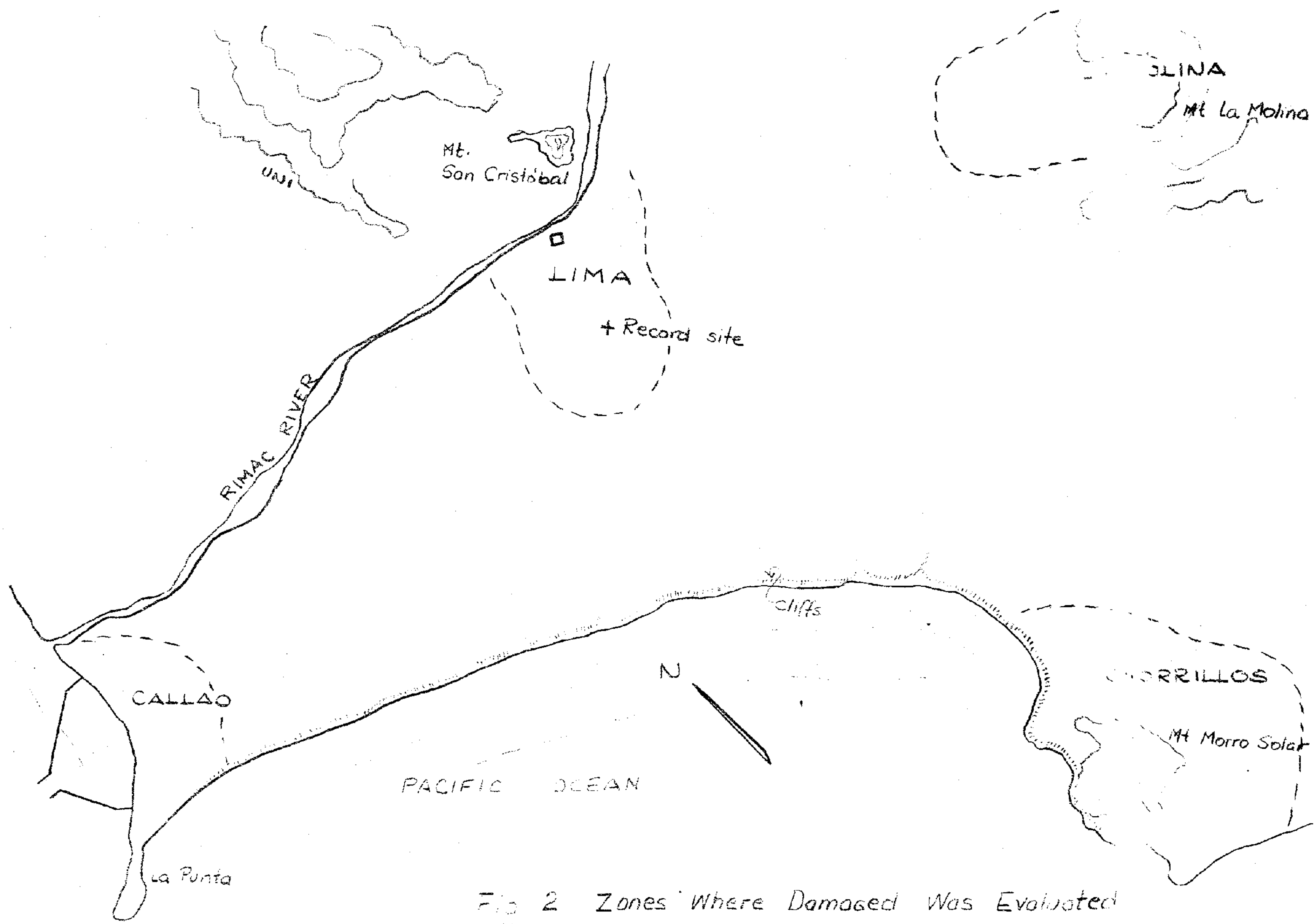


Fig 2 Zones Where Damaged Was Evaluated

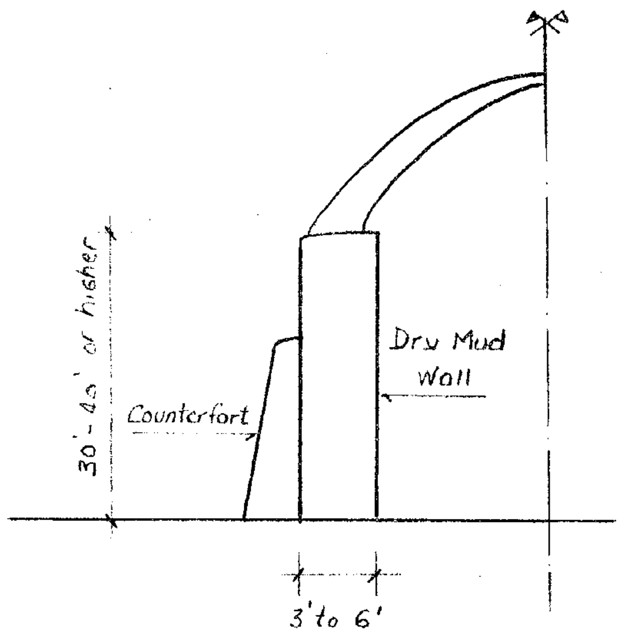


Fig. 3. Massive Mud Wall. Type A1 Construction

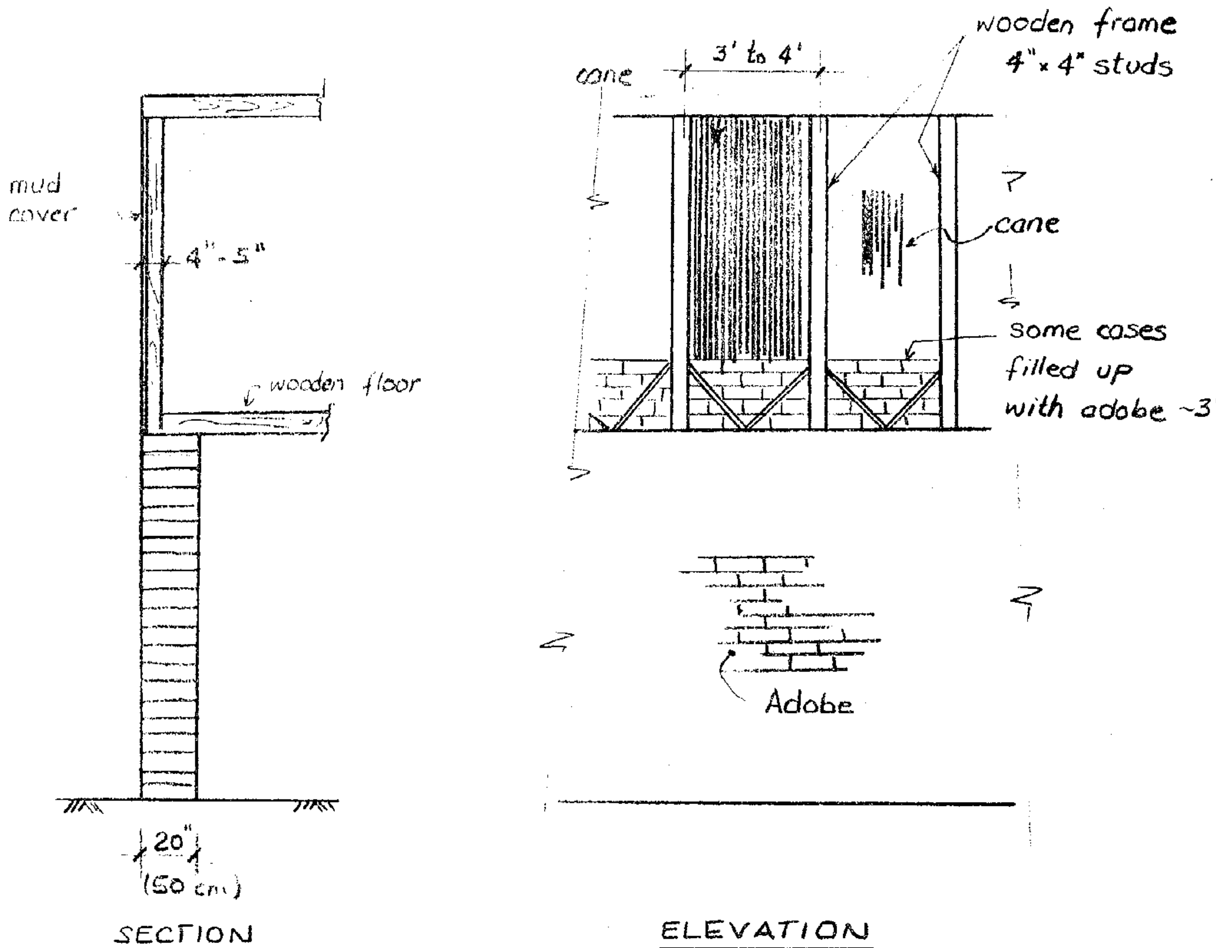


Fig 4. "Quincha". Type A3 Construction

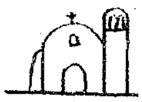
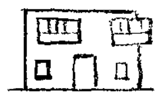
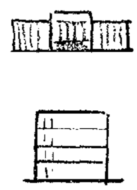
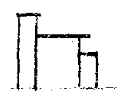
TYPES					
	1	2	3	4	5
"A"	Massive Mud Wall	Adobe	Adobe plus "quincha"	Masonry	Concrete Frame.
Non-Engineered Buildings	Churches, Old Public Bldgs. 	Houses 	Old Houses or Old Condominiums 	Houses 	Public Bldgs. Office Bldgs. Condominiums (1930-1960) 
"B"	Masonry	Concrete Frames	Concrete Frames plus Shear Walls	Shear Walls	
Engineered Buildings	Houses 	Office Bldgs Condominiums 	Office Bldgs Condominiums 	Office Bldgs Condominiums 	

Fig. 5. Types of Construction

TABLE 1.

DAMAGE STATES IN MSK SCALE (REF. 2)

Grade 1:	Slight damage: Fine cracks in plaster; fall of small pieces of plaster.
Grade 2:	Moderate damage: Small cracks in walls; fall of fairly large pieces of plaster; pantiles slip off; cracks in chimneys; parts of chimneys fall down.
Grade 3:	Heavy damage: Large and deep cracks in walls; fall of chimneys.
Grade 4:	Destruction: Gaps in walls; parts of buildings may collapse; separate parts of the building lose their cohesion; inner walls and filled-in walls of the frame collapse.
Grade 5:	Total damage: Total collapse of buildings.

TABLE 2.

SUMMARY OF DAMAGE BY TYPE OF CONSTRUCTION AND LOCATION

	TYPE OF CONSTRUCTION	LIMA	CALLAO	LA MOLINA	CHORRILLOS
NOT ENGINEERED TO RESIST LATERAL FORCES	A1. Massive mud walls	Most slight Many moderate Few heavy	Most slight Many moderate	Most heavy	Most heavy
	A2. Adobe	Most moderate Many heavy	Some moderate Many heavy Some collapse	Some moderate Many heavy Some* collapse	Some moderate Some heavy Many collapse
	A3. Adobe plus reinforced "qunicha"	Many slight Many moderate Few collapses	Many moderate Many heavy Few collapse		Many heavy Some collapse
	A4. Clay bricks	Few slight	Many slight	Many slight Few moderate	Many slight
	A5. Concrete frame	Many slight	Many slight Few moderate		Many slight
ENGINEERED TO RESIST LATERAL FORCES	B1. Clay brick plus R.C. Columns	Few slight	Few slight	Many slight Many moderate	Some slight
	B2. Concrete frame	Most slight Many moderate	Many slight Some moderate Few collapsed	Some moderate Many heavy Some collapse	Most heavy
	B3. Concrete frame and shear wall	Most slight Many moderate	Many slight Some moderate		
	B4. Box construction	Many slight Few moderate			
Estimate by others of intensity on Modified Mercalli scale.		VII	VII to VIII	VIII	VIII
M.I.T. estimate of intensity on MSK scale		VII	VII to VIII	VII-VIII	VIII

(*) Some → ~30%

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