EARTHQUAKE ENGINEERING RESEARCH CENTER

INFLUENCE OF SITE CHARACTERISTICS ON BUILDING DAMAGE DURING THE OCTOBER 3, 1974 LIMA EARTHQUAKE

by

Pedro Repetto

Ignacio Arango

H. Bolton Seed

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INTRODUCTION

The Pacific subduction zone that runs parallel to most of the west coast of South America is the frequent seat of crustal readjustments, which produce large magnitude earthquakes. As a result, the continent has been subjected to more than ten earthquakes larger than Magnitude $M_s = 7$ during the last 75 years. In fact, an earthquake with the highest magnitude ever assigned ($M_s = 8.9$) took place in 1906 near the border of Colombia and Ecuador.

Peru has had its share of large magnitude earthquakes with devastating consequences for the country. In 1970, for example, an $M_s = 7.6$ earthquake killed more than 30,000 persons and caused millions of dollars in property damage.

The city of Lima has been subjected in the past 30 years to six earthquakes with surface wave magnitudes in the range of 6 to 7.6. In spite of ground surface accelerations as high as 20 to 40 percent of gravity, and durations of strong ground motion well over one minute, the earthquakes have caused unusually low levels of damage in the city itself. Furthermore, experience has shown that the damage that does occur within Lima is concentrated in a few areas outside the main center of population.

An earthquake with magnitude $M_s = 7.5$, originating some 90 km west of Lima took place on October 3, 1974, and peak ground accelerations as high as 0.25g were recorded in the city. As during previous events, however, the damage inflicted upon the city was less than that usually observed from such earthquakes in other areas of the world. The damage was concentrated primarily in three sections on the outskirts of the city: to the west, near the city port of Callao, where naval facilities suffered considerable damage; to the east at La Molina where newly built structures of the Universidad Nacional Agraria either collapsed or sustained serious damage; and to the south, in the district of Chorrillos. The October earthquake was followed about one month later by a strong aftershock (M_s = 7.2). Eight components of strong ground motion recordings were obtained during these two events at three locations within the greater Lima area, thus providing a good indication of the amplitudes of the earthquake ground motion in the city. Shortly after the earthquake, the Government of Peru organized task forces to survey the damage resulting from the earthquake motions.

Since the severity of the ground motion is known, and general data about the damage were available, the 1974 events clearly provide an excellent opportunity for investigators to attempt to explain why damage in Lima is generally lower than in other places of the world subjected to similar earthquakes, and to understand the reasons for the pattern of damage observed as a result of this and previous earthquakes.

To address these questions, an investigation was carried out that included a study of the structural characteristics of buildings in Lima, the damage and the distribution of damaged buildings during the October event, analysis of available data, additional field investigations to classify subsurface conditions and to measure material properties, and an analysis of the strong ground motion data. Specifically, it was desired to find out whether local subsurface conditions could have influenced the damage and the distribution of damage caused by this and previous earthquakes in the Lima area. The results of the investigation form the subject of this report.

THE CITY OF LIMA

Lima, founded by Pizarro in 1535, is one of the oldest cities in the Americas. The new settlement was located a few miles inland from the seaport of El Callao, thereby protecting it from foreign invaders.

Lima and Callao are located on the west coast of Peru in a desertic strip of land bounded by the Pacific Ocean and the Andean Mountains, which rise to altitudes of 4800 m at about 95 km from the shoreline.

The growth of Lima through the colonial and early independent years was rather slow. The population grew around the Callao and Lima centers, expanding along and towards the shoreline in a pattern resembling an inverted T as can be seen in Figure 1, which shows the city limits by the year 1932. The rapid areal growth of the city during the last 50 years can also be observed in the same figure (a ten-fold increase in population and a five-fold increase in areal extension). Topographically, the city is bounded by low-relief hills, which are shown in Figure 1.

CONSTRUCTION PRACTICE

Prevalent construction practice in Lima has changed throughout the years. It is possible, however, to classify existing urban construction within the following three basic types: adobe and/or quincha; brick; and reinforced concrete.

Adobe and/or quincha dwellings are typically 1 or 2 stories high with total heights of 4 or 8 m, respectively. Roof construction is of wood beams with a cover of mud, supported on adobe or quincha walls. Dwellings of this kind are typically 50 to more than 100 years old. The structural condition of these dwellings must have been rather poor by the time of the 1974 event, since the earthquakes in 1940, 1966, and 1970 undoubtedly damaged and weakened these structures.

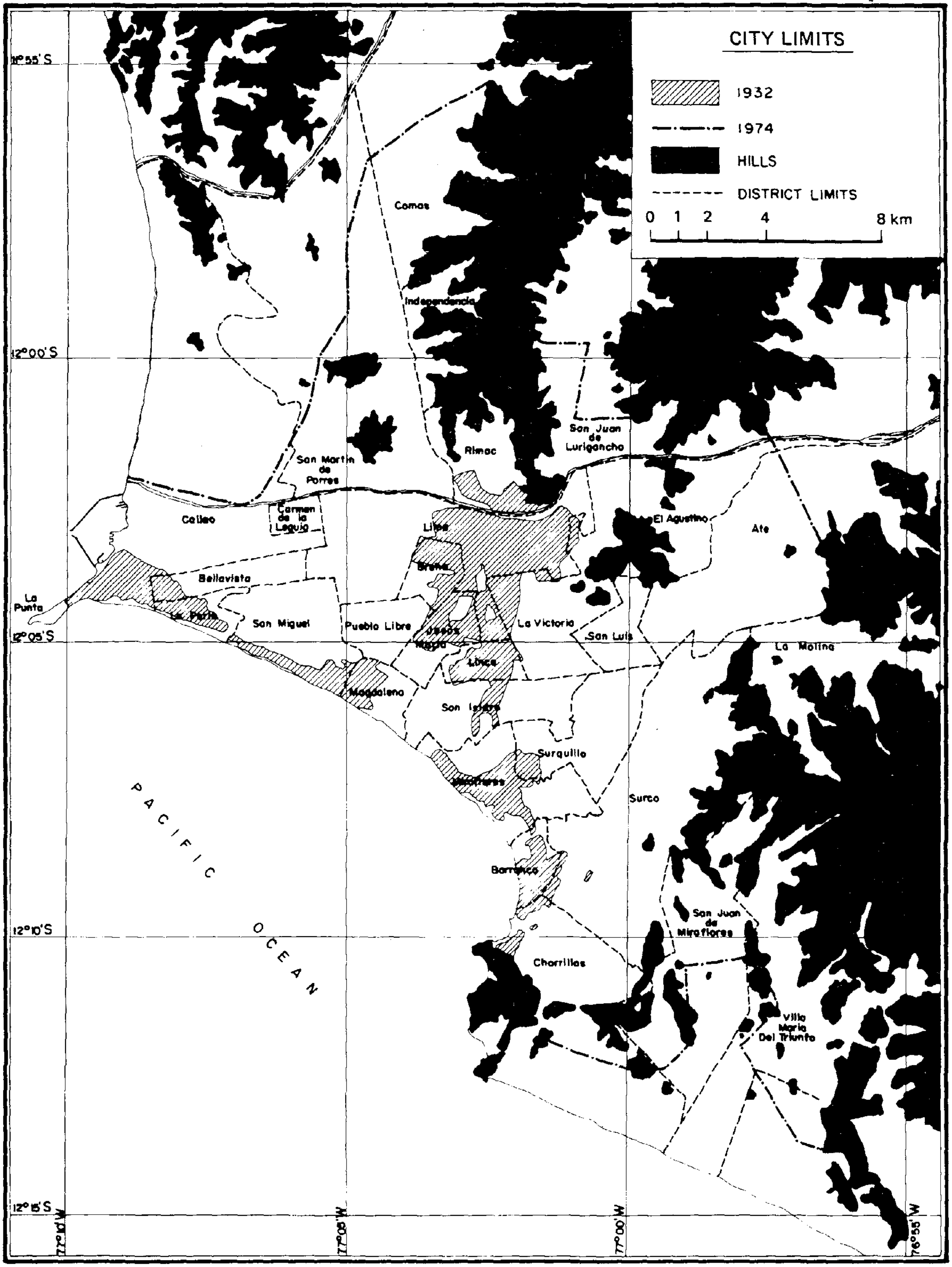

Fig. 1 – CITY LIMITS, GREATER LIMA

While some adobe construction is spread throughout Lima, most of it is concentrated within the oldest districts of the town, and along a few avenues connecting high population centers. This is the inverted T pattern shown in Figure 1, which corresponds to the limits of the city by 1932. Large concentrations of adobe construction are seen today in the districts of Rimac, Chorrillos, Lima, Barranco, Pueblo Libre, Magdalena, Miraflores, and Callao (see Figure 1).

Brick and concrete dwelling construction in Lima dates back some 50 years. Buildings are typically 1 to 3 stories high. Roofs and intermediate floors consist of reinforced concrete slabs (with hollow brick infill to decrease dead weights), supported on 25-cm-wide brick bearing walls, with no structural continuity between slab and wall. Within the past 10 to 15 years, in order to provide confinement to the walls, reinforced concrete columns have been placed at the wall corners, and a continuous beam has been poured along the wall contacts with the floor slab or ceiling. These construction details make brick dwellings quite rigid, with structural periods typically within the range of 0.10 to 0.20 seconds.

Buildings in excess of 3 stories are usually of the reinforced concrete frame type. Design provisions incorporating lateral force effects were not required in Peru until about 20 years ago, but even when they were introduced, the standard of practice was considerably below the requirements specified in the current Peruvian Code, and in many modern building codes. It can perhaps be stated that only in the last 10 years has the design of structures in Peru been truly earthquake resistant (2)*.

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*Numbers in parentheses indicate corresponding references at the end of the report.

Modern Lima has expanded to the limits indicated in Figure 2. Zones of the city marked as "totally constructed" indicate sectors of the city where building construction is quite dense; there are practically no vacant lots. Sections of the city with more sparsely distributed construction are also indicated in the same figure. The majority of the post-1932 buildings constructed in the greater Lima area consist of 1- to 2-story brick constructions. Zones with high concentrations of multi-story buildings (3 or more stories) have been shown in Figure 3. These newer structures have replaced older adobe dwellings, in particular in the old section of Callao and Lima (Figure 1) and along the main avenues of the city.

THE EARTHQUAKE AND ITS AFTERSHOCK

The U.S. Geological Survey (1) lists the magnitude of the October 3, 1974, earthquake as $M_s = 7.5$, with an epicenter about 90 km from the center of Lima. The focal depth was determined to be about 13 km. Two stations recorded the ground motion as follows:

Station	Epicentral Distance	Maximum Acceleration
Geophysical Institute	86 km	0.25g
Huaco Residence	91 km	0.25g

This earthquake was followed on November 9, 1974, by an $M_s = 7.2$ (USGS) aftershock that was recorded at two stations as follows:

Station	Epicentral Distance	Maximum Acceleration
Geophysical Institute	95 km	0.08g
La Molina	103 km	0.14g

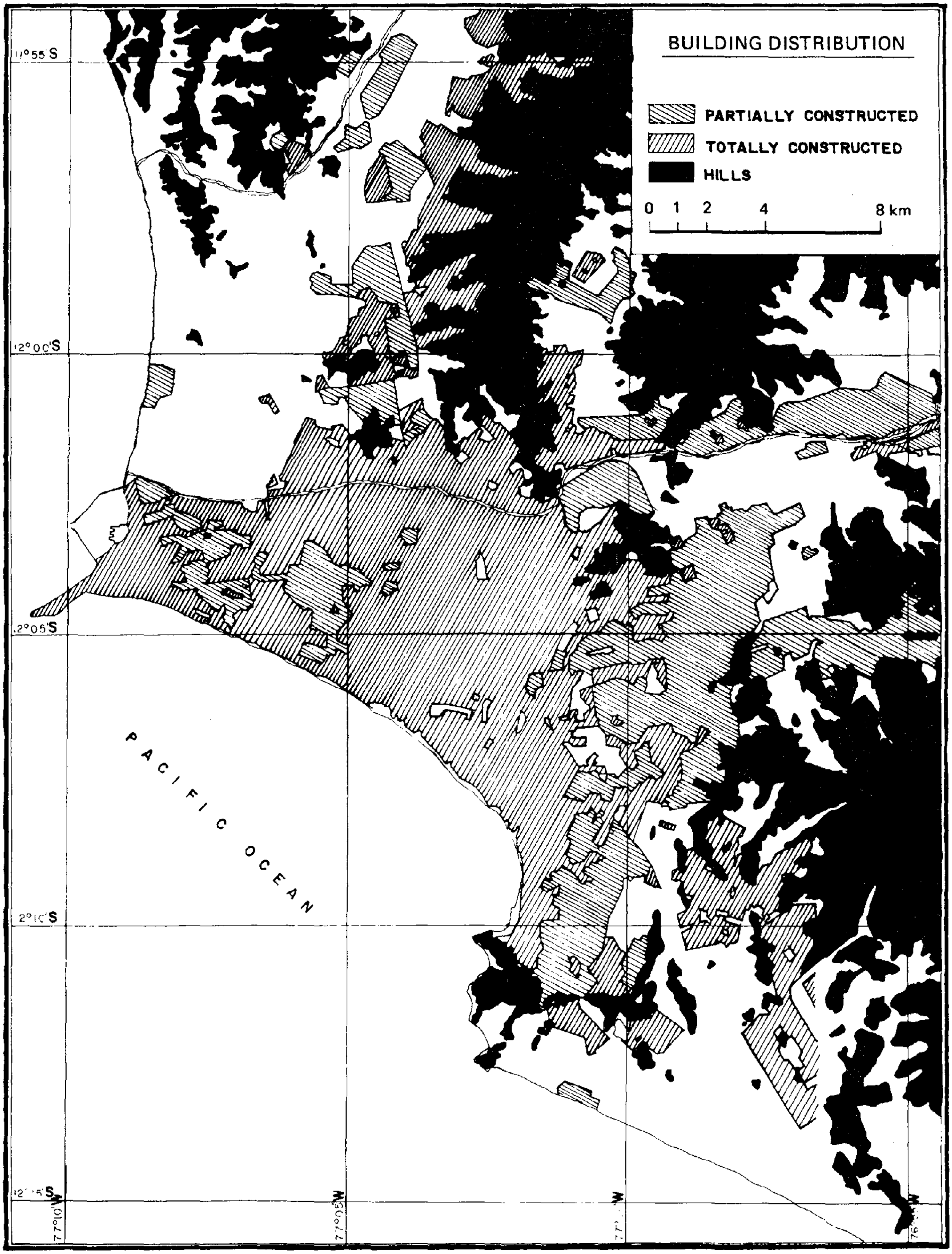


Fig. 2 – BUILDING DISTRIBUTION, GREATER LIMA

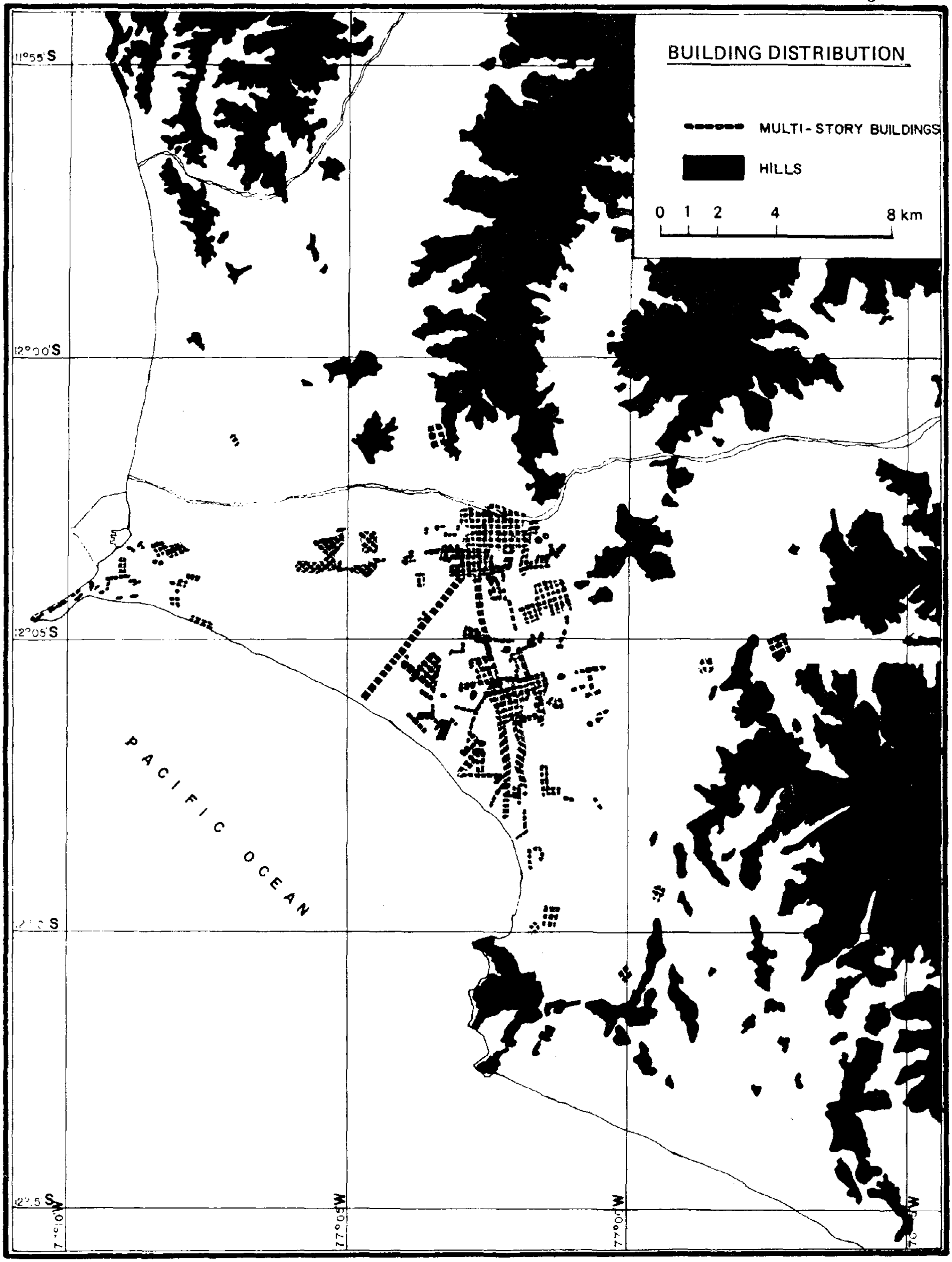


Fig. 3 – BUILDING DISTRIBUTION, GREATER LIMA

Shortly after the October earthquake, a field investigation was conducted by Husid and others (4) from the U.S. Geological Survey, with the purpose of evaluating the intensity of damage in Lima and vicinity. In this study questionnaires were distributed throughout the city and used to assign Modified Mercalli Intensities to different parts of the city (8). A total of 400 reports were obtained and the information processed to develop an isoseismal map showing the intensity distribution in metropolitan Lima. This map is reproduced in Figure 4. The field evaluation led Husid et al. (4) to conclude that "there was a definite correlation of high intensity ratings with areas that have high water tables and springs or unfavorable soil subsurface conditions, coupled with possible local ground-amplification effects."

A comparison of the areas of highest intensity (VII or greater) shown in Figure 4 (taken from Husid et al.) and reproduced in Fig. 5 with Figures 1 and 3 of this study shows that the zones with the highest MM Intensity rating coincide remarkably well with the area known to have the oldest and most abundant quincha and adobe construction (Figure 1) in existence prior to 1932. At the outset of this investigation therefore, it was considered necessary to isolate structural effects from other factors that may have been indicative of the influence of local subsurface conditions on the type and distribution of damage in the Lima area. For this purpose, a field damage study within the area of highest intensity identified in Figure 4 was carried out. The results of the study are presented in the following section.

SURVEY OF DAMAGE IN AREAS OF APPARENT HIGHEST INTENSITY

Damage surveys were undertaken in five zones selected for the field work, zones which were considered representative of the general conditions

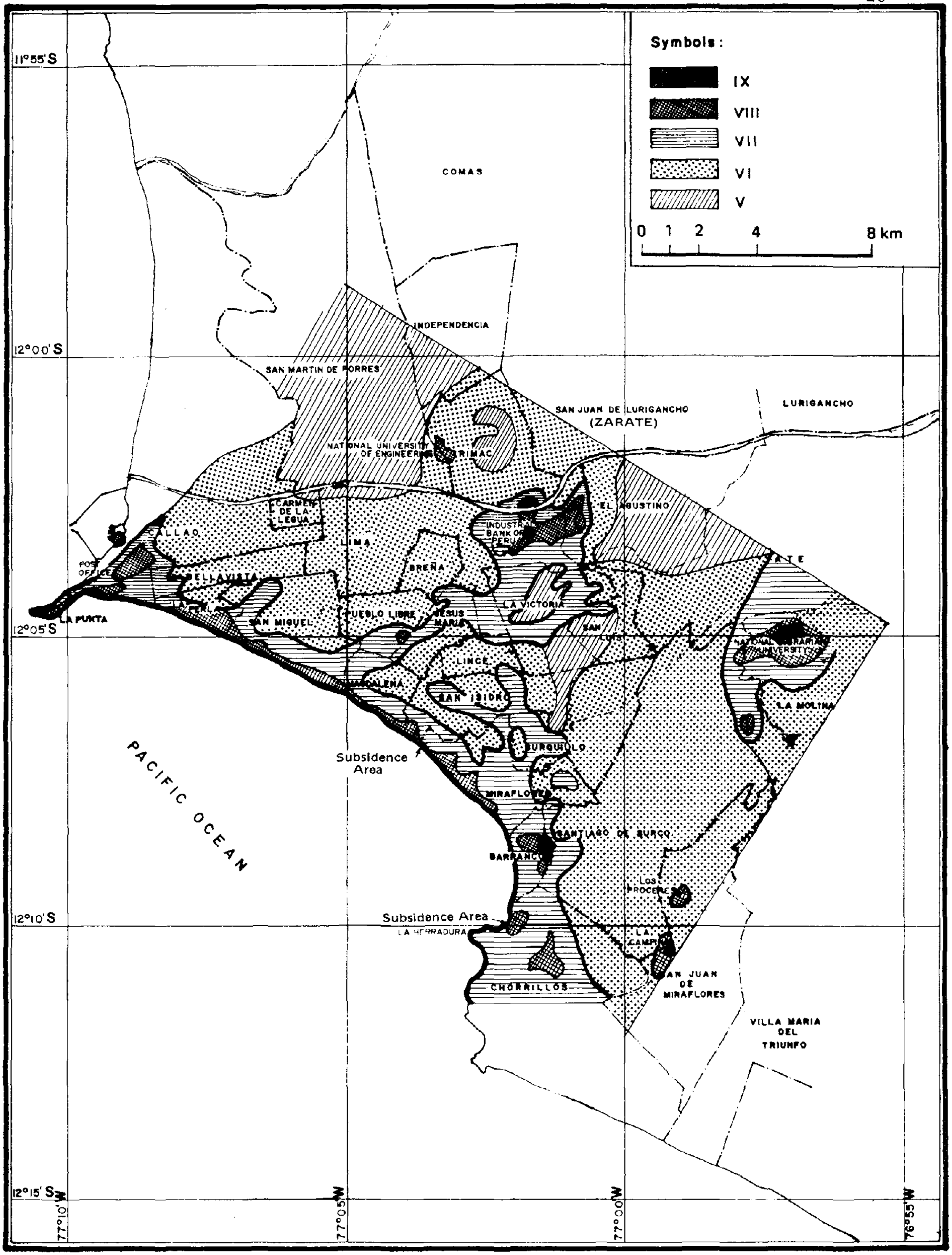


Fig. 4 – MODIFIED MERCALLI INTENSITY DISTRIBUTION
(From Husid et al.)

throughout the MM Intensity > VII region. The locations of these zones are shown on Figure 5. Data were gathered on the damage characteristics and on the statistics of the various construction types. (Sample Areas 6 and 7, also shown in Figure 5, were used for a separate purpose, which will be discussed later in this report.)

Table 1 presents a summary of the areas of each of the five zones investigated and the types of buildings in each zone, classified with respect to construction type and building height. The table shows, for example, that the smallest sampled area, Miraflores 2, was about six city blocks in area and contained 92 buildings. The largest sample area was located in the district of Lima (30 city blocks containing 77 buildings).

Damage to surveyed structures was rated according to the following convention:

Light:	Moderate amounts of haircracks.
Moderate:	Moderate amount of thin cracks, or a few thick cracks.
Severe:	Moderate to large amount of thick cracks. Walls out of plumb.
Collapse:	Walls fallen, roofs distorted.

The information compiled is shown in Tables 2 through 6. As a whole, 80 city blocks, with a total of 1824 buildings within the area of highest damage intensity to adobe construction, were investigated. About 66 percent of the buildings (1195 buildings) were of the adobe type. Of these, 139 totally collapsed, 503 suffered severe damage, and 378 others showed light to moderate damage, indicating that about 54 percent of the adobe construction either collapsed or suffered severe damage due to the earthquake shaking.

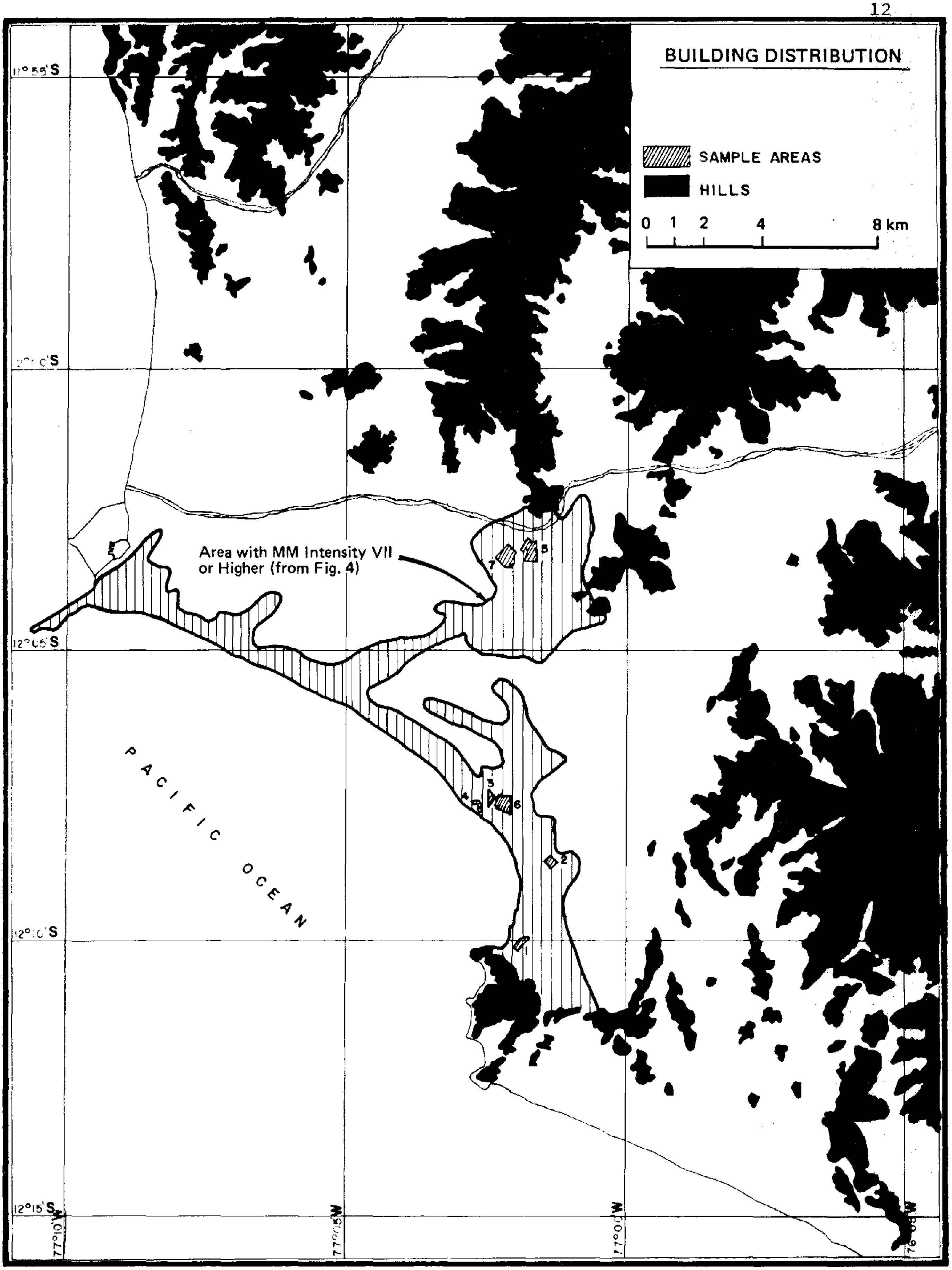


Fig. 5 – SAMPLE AREAS LOCATION, GREATER LIMA

TABLE 1. BUILDING DISTRIBUTION IN SAMPLE AREAS OF CONCENTRATED DAMAGE TO ADOBE CONSTRUCTION

Sample Area No.	District	Sample Area (Ha)	Adobe	Brick and Concrete (Bearing Walls)		Brick and Concrete (Framed)			Other	Total
			1-2 Story	1-2 Story	3 Story	1-2 Story	3-4 Story	5-6 Story		
1	Chorrillos	9.2	157	118	14	2	3	-	19	313
2	Barranco	9.9	311	126	3	3	-	-	19	462
3	Miraflores 1	6.0	147	31	4	-	2	-	1	185
4	Miraflores 2	4.2	68	17	4	-	-	-	3	92
5	Lima	20.9	512	221	15	-	5	1	18	772
Total		50.2	1195	513	40	5	10	1	60	1824
Percentage			66	28	2	-	1	-	3	100%

Note: One Ha ≈ one and a half city blocks

TABLE 2. DAMAGE DISTRIBUTION IN SAMPLE AREA OF CONCENTRATED DAMAGE TO ADOBE CONSTRUCTION: CHORRILLOS

	Damage						
	None	Light	Moderate	Severe	Collapse	No Inform.	Total
Adobe 1-2 story	--	3	6	49	79	20	157
Bearing walls 1-2 story	52	25	7	10	--	24	118
Bearing walls 3 story	7	4	-	--	--	3	14
Framed 1-2 story	1	1	-	--	--	--	2
Framed 3-4 story	--	2	1	--	--	--	3
Framed 5-6 story	--	--	-	--	--	--	--
Other	--	--	-	--	--	19	19
Total	60	35	14	59	79	66	313

TABLE 3. DAMAGE DISTRIBUTION IN SAMPLED AREA OF CONCENTRATED DAMAGE TO ADOBE CONSTRUCTION: BARRANCO

		Damage						
		None	Light	Moderate	Severe	Collapse	No Inform.	Total
Adobe	1-2 story	15	18	56	173	30	19	311
Bearing walls	1-2 story	77	27	1	3	--	18	126
Bearing walls	3 story	2	1	--	--	--	--	3
Framed	1-2 story	3	--	--	--	--	--	3
Framed	3-4 story	--	--	--	--	--	--	--
Framed	5-6 story	--	--	--	--	--	--	--
Other		--	--	--	--	--	19	19
Total		97	46	57	176	30	56	462

TABLE 4. DAMAGE DISTRIBUTION IN SAMPLED AREA OF CONCENTRATED DAMAGE TO ADOBE CONSTRUCTION: MIRAFLORES-1

		Damage						
		None	Light	Moderate	Severe	Collapse	No Inform.	Total
Adobe	1-2 story	15	58	26	11	4	33	147
Bearing walls	1-2 story	21	3	--	--	--	7	31
Bearing walls	3 story	3	1	--	--	--	--	4
Framed	1-2 story	--	--	--	--	--	--	--
Framed	3-4 story	1	1	--	--	--	--	2
Framed	5-6 story	--	--	--	--	--	--	--
Other		--	--	--	--	--	1	1
Total		40	63	26	11	4	41	185

TABLE 5. DAMAGE DISTRIBUTION IN SAMPLED AREA OF CONCENTRATED DAMAGE TO ADOBE CONSTRUCTION: MIRAFLORES-2

		Damage						
		None	Light	Moderate	Severe	Collapse	No Inform.	Total
Adobe	1-2 story	3	21	23	4	--	17	68
Bearing walls	1-2 story	3	11	--	-	--	3	17
Bearing walls	3 story	1	3	--	-	--	--	4
Framed	1-2 story	-	--	--	-	--	--	--
Framed	3-4 story	-	--	--	-	--	--	--
Framed	5-6 story	-	--	--	-	--	--	--
Other		-	--	--	-	--	3	--
Total		7	35	23	4	--	23	92

TABLE 6. DAMAGE DISTRIBUTION IN SAMPLED AREA OF CONCENTRATED DAMAGE TO ADOBE CONSTRUCTION: LIMA

		Damage						
		None	Light	Moderate	Severe	Collapse	No Inform.	Total
Adobe	1-2 story	3	64	103	266	26	50	512
Bearing walls	1-2 story	84	101	13	2	--	21	221
Bearing walls	3 story	11	4	--	--	--	--	15
Framed	1-2 story	--	--	--	--	--	--	--
Framed	3-4 story	4	1	--	--	--	--	5
Framed	5-6 story	--	1	--	--	--	--	1
Other		--	--	--	--	--	18	18
Total		102	171	116	268	26	89	772

Within the same area, there were 569 other structures of the brick-bearing-wall and reinforced concrete frame types. Of these, 166 had light to moderate damage, and only five showed evidence of severe damage; or, stated in a different manner, less than 1 percent of these structures suffered severe damage during the earthquake. Clearly therefore the type of structure and the quality of construction must be realistically considered in assigning ground shaking intensities to any region affected by earthquake shaking.

Since the damage to adobe-type construction was observed wherever this type was present regardless of geographic location within the greater Lima area, it is clear that this damage cannot be taken as an indicator of the potential effect of local subsurface conditions on the damage itself. Attention was therefore directed to the performance of brick-bearing-wall and R.C. frame structures as a means of identifying damage patterns and their distribution within the study area. The results of this investigation are described in the following section.

BRICK-BEARING-WALL AND R.C. FRAME BUILDINGS: EVALUATION OF DAMAGE

A primary goal of the investigation thus became the identification of all brick-bearing-wall and R.C. frame structures known to have experienced important damage during the October 1974 earthquake. As a result of the investigation, a listing of all identifiable damaged structures was prepared, including information obtained from available published reports on the earthquake, various government agency public files, and files from a large number of private consulting engineers and architects with ample experience in the city.

From the outset of the investigation, it was clearly necessary to rate the varying degrees of damage to the structures in a systematic format. For this purpose, the scale of damage intensity I_d proposed by Repetto and Zegarra (7) was adopted. The scale, Table 7, is divided into ten intensity degrees varying from no damage, $I_d = 1$, to total collapse, $I_d = 10$. Intensity 4 corresponds to incipient structural damage (cracking in about 10 percent of the beams and walls), and was adopted as the minimum damage to be considered in this study.

Following this criterion, it was possible to identify 96 structures in the entire greater Lima area showing evidence of damaged structures equal to 4 or greater. Table 8 shows the distribution of the damaged structures by damage intensity and geographic district, while Table 9 identifies the structures by name, number of stories, and damage intensity, providing also an identification number through which the structures can be located within the Lima area with the help of the map shown in Figure 6. A summary of the number of damaged buildings, in relation to story height and damage intensity in the different districts of Lima is shown in Table 10.

Some of the structures that suffered damage with intensity 4 or greater were within groups of other structures with damage intensities below 4. Clearly, it was of interest to gather information about the relatively undamaged structures since further light on the cause of damage could be obtained by comparing the various structures. As a result, data on 66 additional buildings having damage intensities $I_d < 4$ were gathered, bringing the total number of structures studied to 162.

TABLE 7. STRUCTURAL DAMAGE INTENSITY SCALE

1. No damage.

2. Damage to non-structural elements as parapets, chimneys.

3. Cracking of partition walls. No structural damage.

4. Cracking in up to 10 percent of beams and columns, but no damage to joints in R.C. frames; or cracking in up to 10 percent of bearing walls. Cracking of partition walls.

5. Cracking (without spalling) in up to 25 percent of beam, columns and R.C. joints; or cracking in up to 25 percent of bearing walls. Cracking of partition walls.

6. As in five, but for 50 percent.

7. Cracking in up to 75 percent of beams, columns and R.C. joints. Spalling in 30 percent of the columns. Cracking in 75 percent of the bearing walls, without collapse. Partition walls (up to 25 percent) near collapse.

8. Cracking in most beams, columns and R.C. joints. Spalling in up to 60 percent of the columns. Cracking in most bearing walls. Roofs unlevelled. Partition walls collapse. Poor overall stability.

9. Serious damage in most structural components and partition walls. Partial collapse. Building must be demolished.

10. Total collapse.

(After Repetto and Zegarra)

TABLE 8. DAMAGED BUILDINGS (Id $\geq$ 4) - DAMAGE INTENSITY IN VARIOUS DISTRICTS OF LIMA

District	Damage Intensity							Total
	4	5	6	7	8	9	10	
Ate	8	-	1	-	2	-	-	11
Breña	-	-	1	-	-	-	-	1
Callao	1	3	2	-	-	1	1	8
Chorrillos	-	5	1	6	1	1	-	14
El Agustino	6	-	-	-	-	-	-	6
La Molina	5	7	4	9	2	-	3	30
La Punta	1	1	-	1	1	-	1	5
Lima	1	-	1	-	-	-	-	2
Lince	1	-	-	-	-	-	-	1
Miraflores	-	1	-	-	-	-	-	1
San Isidro	1	-	-	-	-	-	-	1
Surco	9	7	-	-	-	-	-	16
Total	33	24	10	16	6	2	5	96

TABLE 9. LIST OF DAMAGED BUILDINGS

District	No.	Building	Stories	Id
Ate		Recoleta School:		
	1-7	•Classroom buildings	1	4
	8	•Office buildings	2	8
	9	•South Community building	2	8
	10	•North Community building	2	4
		Roosevelt School:		
	11	•Gymnasium	1	6
Breña	12	Scala Offices	2	6
Callao	13	Post Office	2	6
		Harbour:		
	14	•Cereal Silos	-	9
	15	•Operations building	7	4
		San José School:		
	16	•Elementary, new building	3	5
	17	Two-story house	2	10
	18	Nicolini mill	8	6
		Warehouses, Oficina Nacional de Apoyo Alimentario:		
	19-20	•Damaged	2	5
Chorrillos		Telephone exchange		
	21	•Plant	1	7
		Guardia Civil (Police) School:		
	22	•Club and officers lodging	3	9
	23	•Command building	2	6
	24	•Communications school	1	7
	25-28	•Other schools	1	7
	29	•Students lodging	3	8

(Continued)

TABLE 9. CONTINUED

District	No.	Building	Stories	Id
	30	·Troop lodging	3	4
	31	·Kitchen and dining room	1	5
	32-33	·Horses studs	1	5
	34	·Hospital	2	5
El Agustino	35-40	Textiles factory Nuevo Progreso	1	4
La Molina	41	Two-story house	2	10
		Reyna de los Angeles School:		
	42-43	·Classroom buildings	2	8
	44	·Administration building	2	4
	45-46	·Kinder buildings	1	4
	47	·Convent	3	7
	48-51	Indu-Perú	3	6
		National Agrarian University:		
	52	·Library	4	5
	53-56	·Schools	3	7
	57-58	·Laboratories	1	5
	59	·Dining room	1	7
	60-61	·Classrooms	1	10
	62	·Corn school, workshop	1	7
	63	·Experimental market	2-5	4
	64-66	·General services	1	5
		Villa María School:		
	67	·Building A	1	5
	68	·Administration building	2	4
	69	·Junior College	2-3	7
		Agriculture Experiment Station:		
	70	·Potato International Center	2	7

(Continued)

TABLE 9. CONTINUED

District	No.	Building	Stories	Id
La Punta	71	8-story building	8	7
		Navy School:		
	72	·Laboratories	4	5
	73	·Stairways (Classrooms - laboratories)	4	4
	74	·Troop building	4	8
	75	·Students building	4	10
Lima	76	·6-story building	6	4
	77	National Stadium-Tribune	3	6
Lince	78	Automobile Club building	4	4
Miraflores	79	Hipotecario Bank	12	5
San Isidro	80	La Vitalicia building	8	4
Surco		Los Próceres development:		
	81-89	·Stores	2	4
	90-96	·5-story buildings	5	5

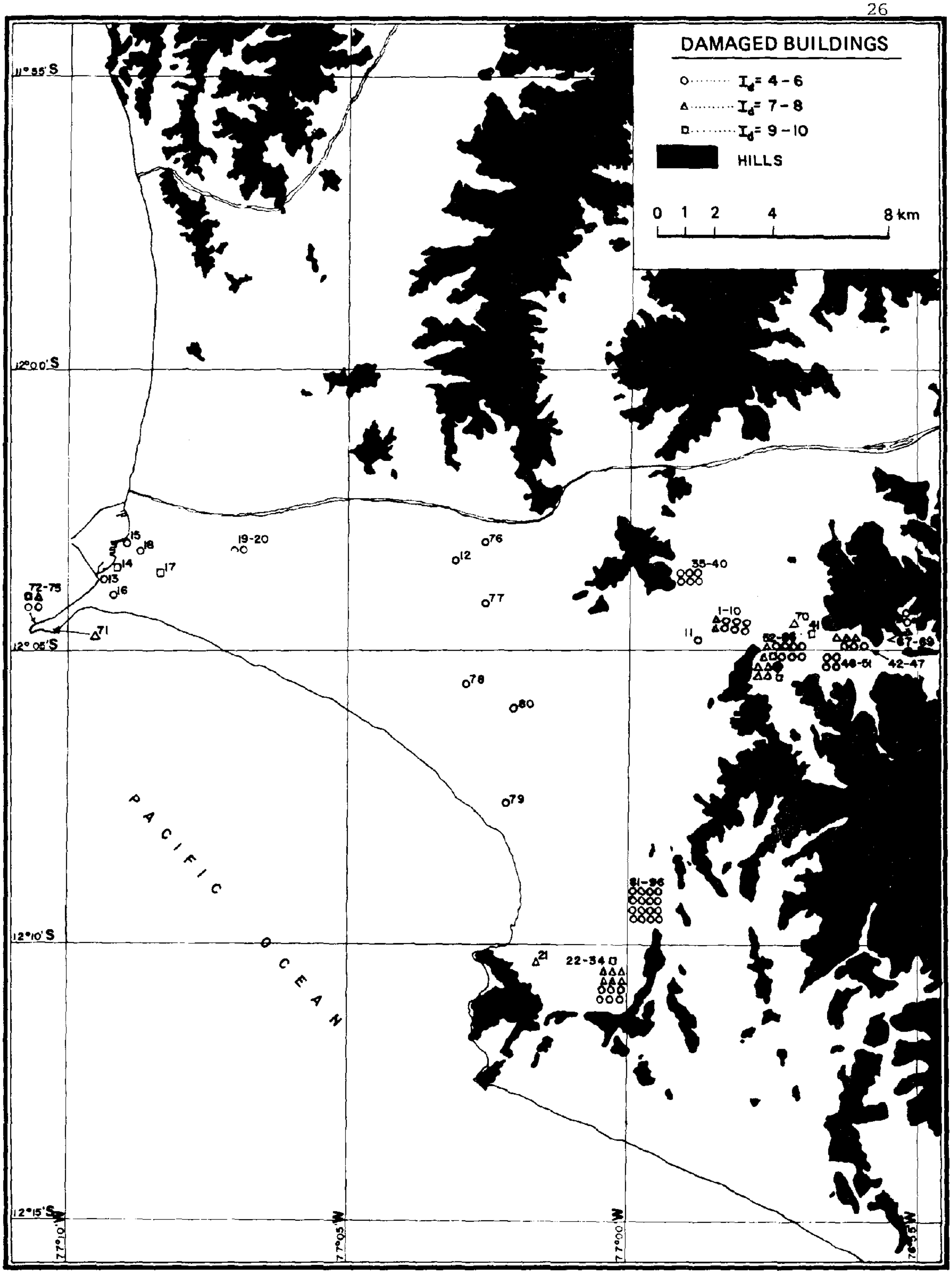


Fig. 6 — LOCATION OF DAMAGED BUILDINGS, GREATER LIMA

TABLE 10. DAMAGED BUILDINGS ($Id \geq 4$) - NUMBER OF STORIES FOR BUILDINGS IN DIFFERENT DISTRICTS

District	Number of Stories						Total	Id Average
	1-2	3-4	5-6	7-10	>10	Other		
Ate	11	-	-		-	-	11	4.9
Breña	1	-	-	-	-	-	1	6.0
Callao	4	1	-	2	-	1	8	6.3
Chorrillos	11	3	-	-	-	-	14	6.4
El Agustino	6	-	-	-	-	-	6	4.0
La Molina	19	11	-	-	-	-	30	6.3
La Punta	-	4	-	1	-	-	5	6.8
Lima	-	1	1	-	-	-	2	5.0
Lince	-	1	-	-	-	-	1	4.0
Miraflores	-	-	-	-	1	-	1	5.0
San Isidro	-	-	-	1	-	-	1	4.0
Surco	9	-	7	-	-	-	16	4.4
Total	61	21	8	4	1	1	96	

DISCUSSION ON DAMAGE DISTRIBUTION

Figure 1, in combination with the damage distribution map presented in Figure 6, clearly shows that there are concentrations of damage in three zones within the greater Lima area, as follows:

(1) The Callao-La Punta districts to the west;

(2) The La Molina-Ate districts to the east; and

(3) The Chorillos and south Surco districts to the south.

In fact, it can be seen from Table 10 that 86 percent of the damaged structures studied are located in these three zones. Furthermore, the highest average damage intensities occur in the districts of Callao-La Punta, Chorillos, and La Molina.

Detailed studies of the damage data pertaining to the structures shown in Figure 6 indicated that for some structures the damage resulting from the earthquake could easily be related to structural and/or construction details, or to foundation-related effects rather than the influence of local subsurface conditions on ground shaking intensities. Thus, for example, the following factors could readily be discerned:

(1) Structure No. 21: Chorillos Telephone Exchange. This 1-story, R.C. frame building suffered damage rated as intensity 7. This is the only building of many similar structures that suffered damage in the Chorillos area, thus pointing out that factors other than the general subsurface conditions were the cause of the damage, (torsional effects due to structural assymmetry).

(2) Structures 35 to 40: Nuevo Progreso Textile Factory. This is a complex of six identical 1-story R.C. frame structures that suffered identical, repeated damage ($I_d = 4$), consisting of

moderate cracking of flexible secondary columns. No other structures in the area had any significant damage ($I_d << 4$) indicating the likelihood of a design defect as the cause of damage.

(3) Structures 48 to 51: Indu-Peru Buildings. These four reinforced brick bearing wall structures were the only buildings showing damage in the area. The damage to the buildings consisted of considerable cracking of the brick-bearing walls ($I_d = 6$), but cannot be considered representative of an influence of subsurface conditions on ground shaking intensity, (damage probably related to deficient steel/concrete bond).

(4) Structures 81 to 89: Los Proceres development, 2-story stores. Damage suffered by these buildings consisted mainly of extensive cracking of exterior double walls, constructed for decoration purposes. The outer brick skin was not properly anchored.

(5) Structures 90 to 96: Los Proceres development, 5-story buildings. These seven buildings suffered identical, repeated damage ($I_d = 5$), consisting of cracking of one type of beam, due to the provision of support for a beam on another beam at a very short distance from a column axis that did not have a secondary frame in the direction of that axis.

In addition to the structures discussed above, Figure 6 shows six structures (Nos. 12, and 76 through 80) located in the central area of greater Lima, which deserve special consideration. These six structures are all of the R.C. frame type, 3 to 12 stories high, with brick walls, and foundations supported on spread footings. Observed damage consisted of cracked beams and columns (I_d = 4 to 6). The question arises as to whether the type of structure typified by these buildings is particularly vulnerable to earthquake ground motions in the central zone of Lima, as suggested by these data.

To clarify this point, a sampling study was made on building distribution in two representative zones of the central area of Lima. The sampling was carried out following the same techniques utilized in the surveys of the areas of high concentration of damage to adobe construction, described in a previous section of this report. The sampling areas were selected in the Miraflores and Lima districts, which are indicated in Figure 5 with the numbers 6 and 7, respectively.

Sample Area No. 6 is located around the Banco Hipotecario in Miraflores (Structure No. 79), a 12-story-high reinforced concrete building that suffered considerable structural damage (I_d = 5) in principal beams at the second story level. As Table 11 shows, the area of 40 city blocks contains 78 buildings 3 to 16 stories high, all of which showed damage intensity $I_d < 4$, thus eliminating any possible relationship between building type and/or height, and local subsurface conditions on ground shaking characteristics.

Sample Area No. 7 was selected adjacent to the 8-story Banco Industrial, in the district of Lima. Damage to this building led Husid et al. to designate the area as MM Intensity IX (see Figure 4). However, this building was classified as damage intensity 2 by Repetto since damage was due to the collapse of a non-reinforced parapet along the facade of the building, which fell onto a cantilevered section of the second floor. A survey of 54 city blocks around the building (see Table 11) disclosed that there are 68 buildings 3 or more stories high in the area, all of which had damage intensity of 3 or lower during the earthquake.

TABLE 11. BUILDING DISTRIBUTION AROUND TWO DAMAGED MULTI-STORY BUILDINGS FOUNDED ON CASCAJO

Sample Area No.			6*	7**
District			Miraflores	Lima
Sample Area (Ha)			25.7	34.7
Adobe	1-2	story	116	104
Materials not determined	1-2	story	32	9
Brick and concrete	1-2	story	126	95
Brick and concrete	3-4	story	32	37
Brick and concrete	5-6	story	9	9
Brick and concrete	7-8	story	14	11
Brick and concrete	9-10	story	8	9
Brick and concrete	11-12	story	10	1
Brick and concrete	13-14	story	3	-
Brick and concrete	16	story	2	-
Brick and concrete	21	story	-	1
Total of Buildings			352	276
Total of Buildings ≥ 3 stories			78	68

* Around Banco Hipotecario (12 stories)

** Around Banco Industrial (8 stories)

One Ha ≃ one and a half city blocks.

It would appear that the damage induced by earthquake shaking in the 33 structures discussed in this section of the report does not follow any soil-related pattern, but rather can be related to structural or constructional details. Eliminating these 33 structures, from the 96 considered in Tables 9 and 10 leaves 63 damaged structures, 52 of which are located in the districts previously identified as having the highest damage concentration and the highest damage intensity rating. Table 12 groups these 63 structures, for which damage is not apparently related to structural details, by districts. Table 13 summarizes the same information with structures grouped in three zones (comprising 4 districts) and gives, in addition, the percentage of damaged structures relative to the estimated total number of similar buildings for the different zones. For comparison purposes, Table 12 also gives the same information for structures located in the areas of greater Lima that are underlain by a dense to very dense, gravelly fluvial material deposited by the Rimac River, locally named "cascajo." The characteristics of the "cascajo" will be described subsequently in greater detail in this report. The damage distribution in the three most affected areas, and in the "cascajo underlain zone," are shown in Figure 7.

Evidence presented in Table 10, and detailed studies by Repetto and Zegarra (7), show that most of the damaged structures are buildings with brick-bearing walls and/or R.C. frame buildings, 1 to 4 stories high, which are quite abundant throughout the greater Lima area. These studies, however, failed to disclose the existence of more damaged structures of these types in addition to those reported in Table 9 and Figure 6.

Having thus established the numbers and locations of damaged structures which appear to be caused solely by strong earthquake shaking and

TABLE 12. DAMAGED BUILDINGS (Id ≥ 4) - NUMBER OF STORIES FOR BUILDINGS IN DIFFERENT DISTRICTS

District	Number of Stories						Total	Id Average
	1-2	3-4	5-6	7-10	>10	Other		
Ate	11	-	-		-	-	11	4.9
Breña	-	-	-	-	-	-	-	-
Callao	4	1	-	2	-	1	8	6.3
Chorrillos	10	3	-	-	-	-	13	6.4
El Agustino	-	-	-	-	-	-	-	-
La Molina	19	7	-	-	-	-	26	6.3
La Punta	-	4	-	1	-	-	5	6.8
Lima	-	-	-	-	-	-	-	-
Lince	-	-	-	-	-	-	-	-
Miraflores	-	-	-	-	-	-	-	-
San Isidro	-	-	-	-	-	-	-	-
Surco	-	-	-	-	-	-	-	4.4
Total	44	15	-	3	-	1	63	

TABLE 13. DAMAGE DISTRIBUTION BY REPRESENTATIVE ZONES

Zone	Number of Damaged Buildings	%*	Id**
La Molina (Lowland)	17	30	6.6
La Campina (Chorillos District)	13	>50	6.4
Callao - La Punta	13	4	6.5
Areas underlain by cascajo***	20	<<<1	4.9
Total	63		

* Relative to estimated total number of similar buildings in the zone, or district.

** Average value, all damaged buildings.

*** Include: Ate, Breña, Lima, Lince, Miraflores and San Isidro districts.

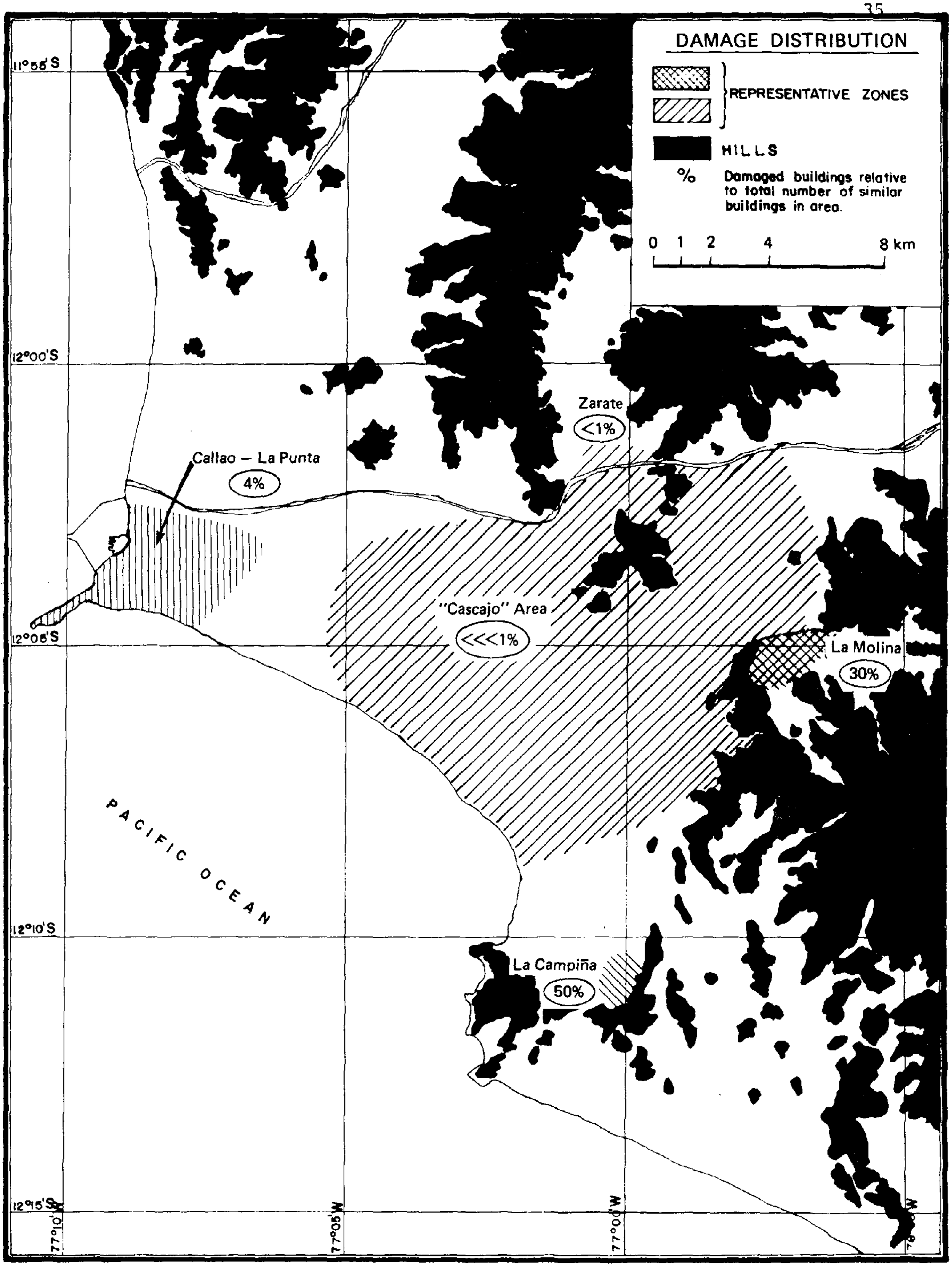


Fig. 7 — DAMAGE DISTRIBUTION, GREATER LIMA

noting that they are indeed concentrated in certain sections of the city, it becomes possible to investigate whether these concentrations are in any way related to local subsurface conditions, which make the response of the ground particularly harmful to these types of structures in these areas. To answer this question, an investigation was carried out with the purpose of finding out the subsurface conditions in the three areas of largest damage concentration and in the area underlain by cascajo where damage was the lowest. Particular attention was given to those factors which experience has shown influence the response of soil deposits to earthquake ground motions. The results of such an investigation are presented in the following section of the report.

SUBSURFACE INVESTIGATIONS

As described previously, greater Lima is located adjacent to the Pacific Ocean on a desertic strip of land bounded to the east by the steep chain of the Andean Mountains. Rain is quite scarce. Rivers coming to the ocean from the Andes are short in length. Surface relief in the valley is gentle, as shown in Figure 8. Greater Lima is founded on the fluvial delta of the Rimas and Chillon rivers and three ancient tributaries: Canto Grande, Pampa Grande, and Pampa Arenal, shown in Figure 8.

Because of its short length, steep gradient and considerable flow, the Rimac River was able to carry in the geologic past a considerable amount of large-diameter material into its delta. The river, emerging into the Lima area a few miles to the east of the city center, meanders back and forth across a triangularly shaped area of land on which most of the city is founded, depositing the "cascajo."

Cascajo is the local name for a sandy, bouldery gravel, poorly graded, but usually very dense, with rounded cobbles and boulders up to 50 cm in diameter. Fines are typically less than 2 percent. Particle

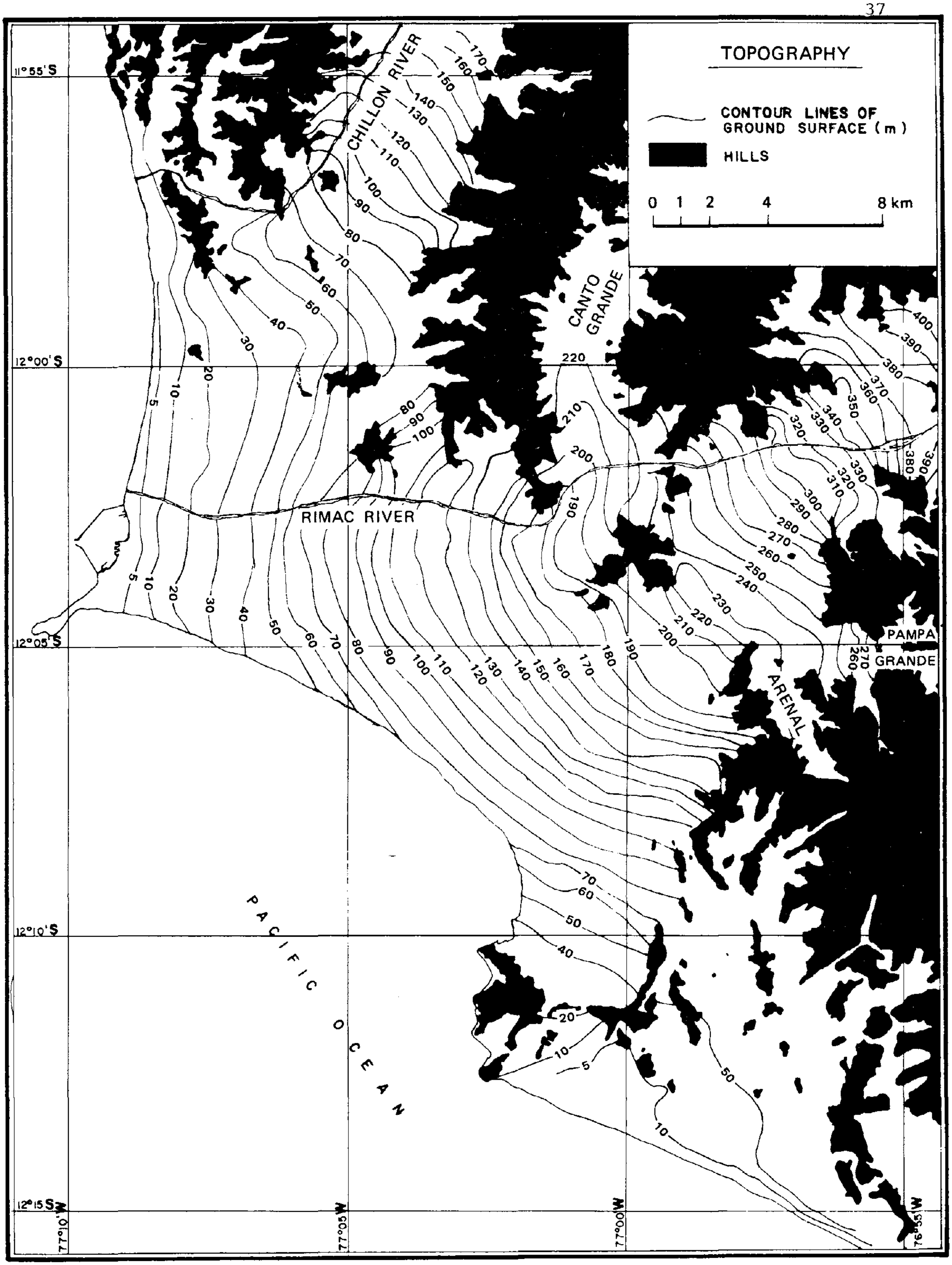


Fig. 8 – TOPOGRAPHY, GREATER LIMA

orientation within the cascajo gives it an apparent cohesion due to grain interlocking, which allows it to be excavated with vertical cuts. The cascajo is exposed along the shoreline, where cliffs 40 to 70 m high with 70- to 80-degree slopes have remained stable for centuries. Typical cascajo properties include an effective friction angle (at moderate vertical loads) greater than 40 degrees; dry unit weights of 2.1 to 2.4 gr/cm^3; specific gravity of solids of 2.66; and in-situ void ratios between 0.1 and 0.3.

Finer material has been carried by the Rimac River toward the districts of Barranco and Chorrillos (to the south) and Callao (to the west). These soil deposits are quite erratic, and contain layers and pockets of medium dense sand, silt, sand and fine gravel, and stiff clays.

North of Callao, the Rimac River deposits blend with those from the Chillon River. Both rivers deposited sands, silts and clays which are, in some areas of Callao and La Punta, underlain at depths by hard marine clay.

Alluvial materials have also been deposited by three ancient tributaries of the Rimac River (see Figure 8). This includes deposits from the Quebrada Canto Grande in the district of San Juan Lurigancho, where the Zarate strong ground motion recording station was located, and deposits from the Quebradas Pampa Grande and Pampa Arenal in the district of La Molina, where the campus of the National Agrarian University is located.

Sediments from these tributaries consist of dense to very-dense sands with occasional angular gravels. The upper 10 m of sands have standard penetration resistance values ranging from 25 blows per foot to refusal.

The low area at La Molina, where the Quebradas Pampa Grande and Pampa Arenal meet, may have been a lake in the past. As a consequence, siltier and more clayey sediments are found in this area to depths on the order of 16 m below the existing ground surface. The sediments have a plasticity index in the range of 40 to 60, and a standard penetration resistance value of 15 to 25 blows per foot. Sands and gravels below the finer material usually have SPT values above 50 blows per foot.

In addition, some areas of greater Lima are blanketed with deposits of aeolian sand carried by southerly winds. These deposits are encountered on the slopes of hills south and east of the city. The Colegio Reyna de los Angeles (structures 42 through 47), for example, is founded on one of these aeolian sand deposits.

To obtain a more accurate picture of the distribution and properties of the various subsurface soils in Lima, the files of geotechnical consulting engineers and the available records on numerous water wells throughout the city were consulted. On the basis of the information obtained, the following well-defined subsurface conditions have been identified in the area (Figure 9):

1. A large central area underlain by cascajo, which consists of a medium dense to very dense coarse gravel and sand with cobbles, extending from the ground surface to rock.
2. Canto Grande (Zarate), deposits, consisting of dense to very dense sands and gravels extending from the ground surface to rock--and very similar in characteristics to the cascajo formation.
3. Callao-La Punta deposits, to the west of the city, consisting typically of sands, silts and clays, underlain by cascajo at

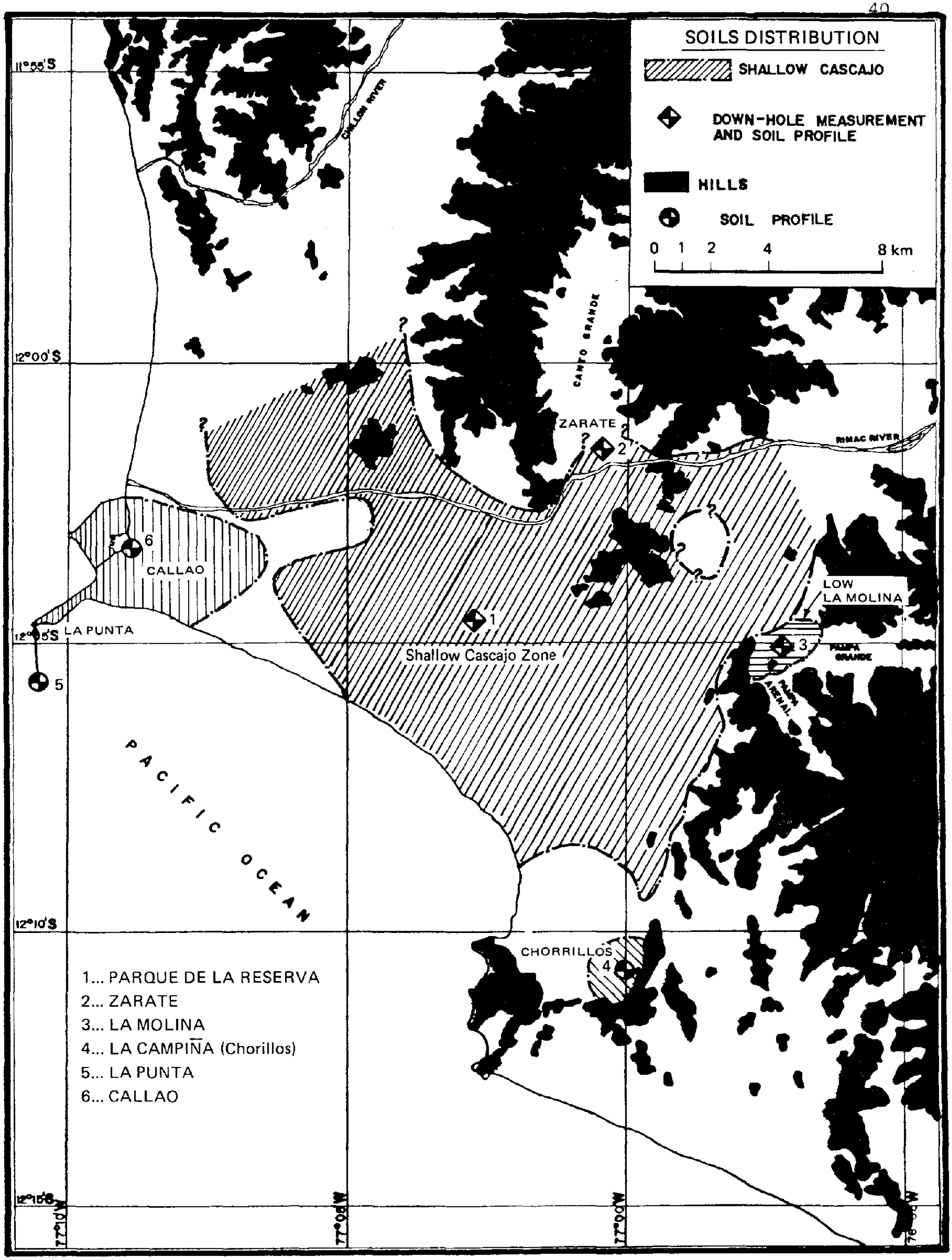


Fig. 9 – SOILS DISTRIBUTION, GREATER LIMA

depths varying from 10 to 30 m, with some hard marine clays at considerable depths in some locations. At La Punta, an open graded cascajo redeposited by the ocean is found at the surface.

4. Low La Molina deposits, consisting of silts and clays, possibly of lacustrine origin, and underlain by dense to very dense sands and gravels.

5. La Campina deposits in the Chorrillos district consisting of fine alluvial material from the Rimac River (silts, clays, sand, occasional fine gravel).

Typical logs of borings depicting the subsurface conditions described above are presented in Figure 10, which also shows the structural damage intensity in the different zones. It is clear that there is a marked difference between the soil conditions in central Lima (and all the cascajo area) where structural damage intensities were very low (much less than 1%) than in the other three areas where deposits of gravel, sand and clay extend to depths of at least 30 m below the ground surface and structural damage intensities range from about 4 to 50 percent.

It is interesting to note that there is no apparent correlation of structural damage intensity in the Lima area with the depth to bedrock (shown in Fig. 11) or the depth of the water table (shown in Fig. 12). The reason for the lack of correlation with depth to bedrock, as will be seen from the following section of the report is that the cascajo behaves for practical purposes, as if it were bedrock. Depth to water table is not usually a significant factor unless soil instability (liquefaction) is involved, and this is not likely to occur in the stiff clays and dense cohesionless soils underlying most of the greater Lima area.

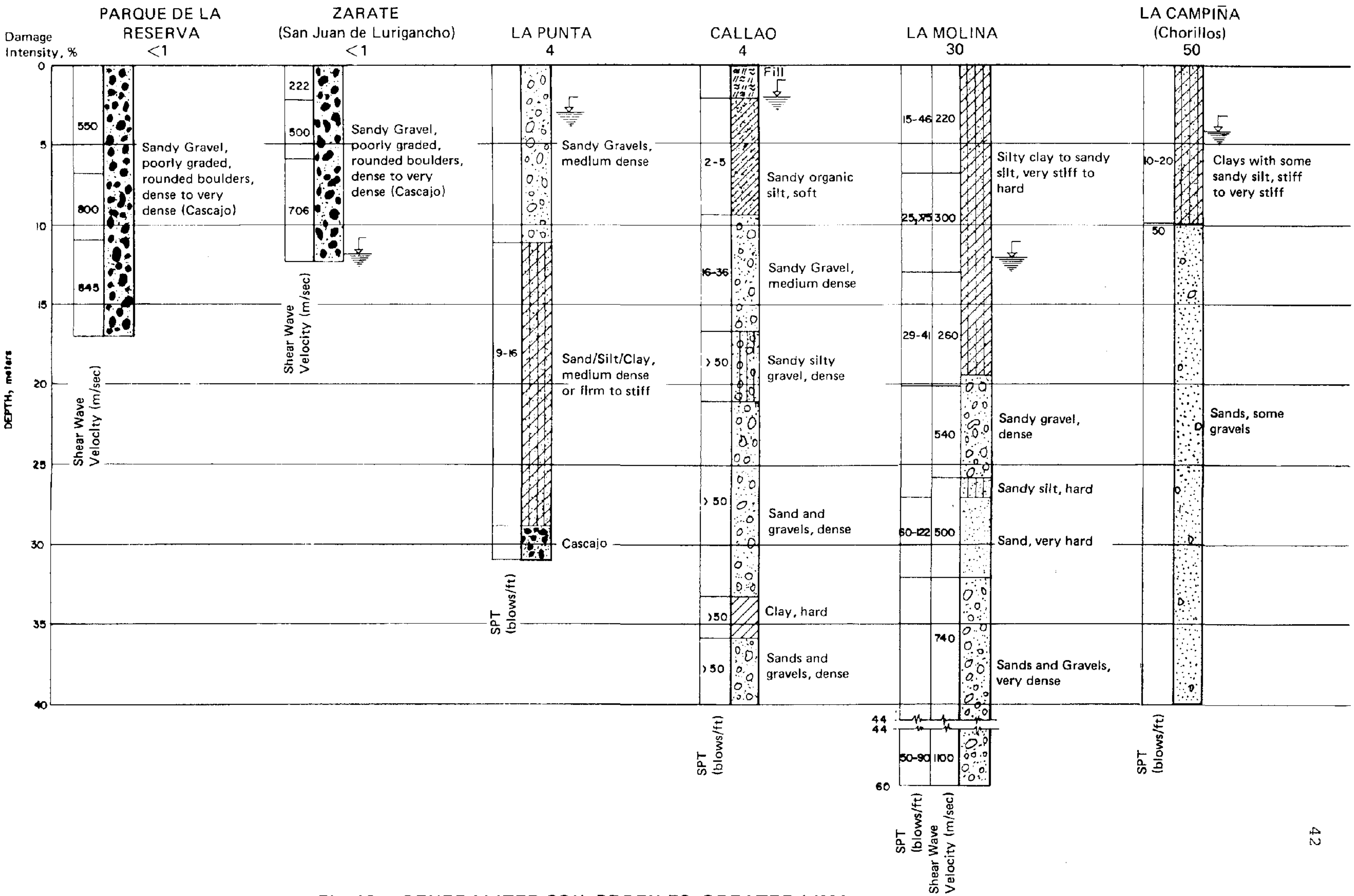


Fig. 10 – GENERALIZED SOIL PROFILES, GREATER LIMA

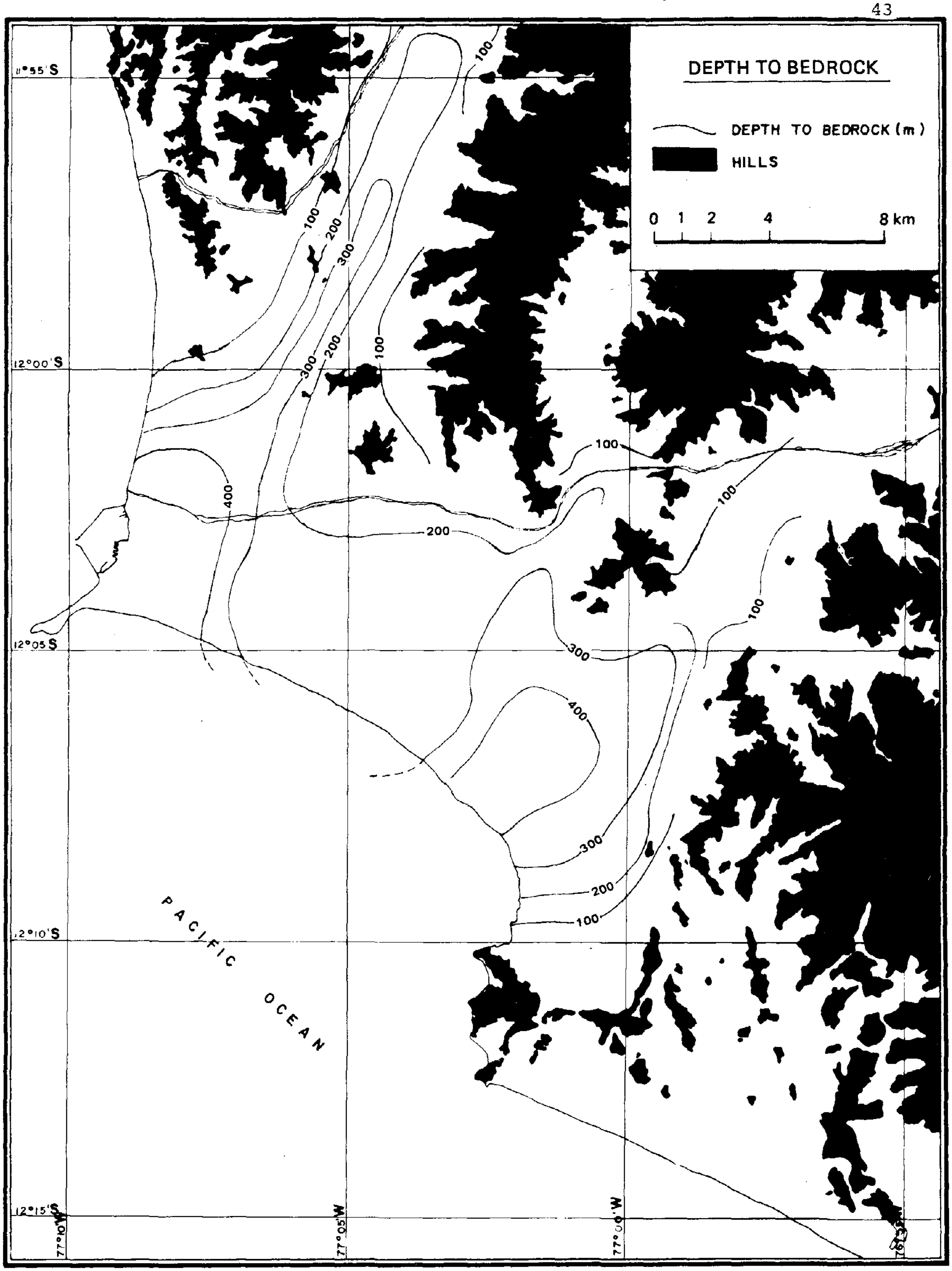


Fig. 11 – DEPTH TO BEDROCK, GREATER LIMA

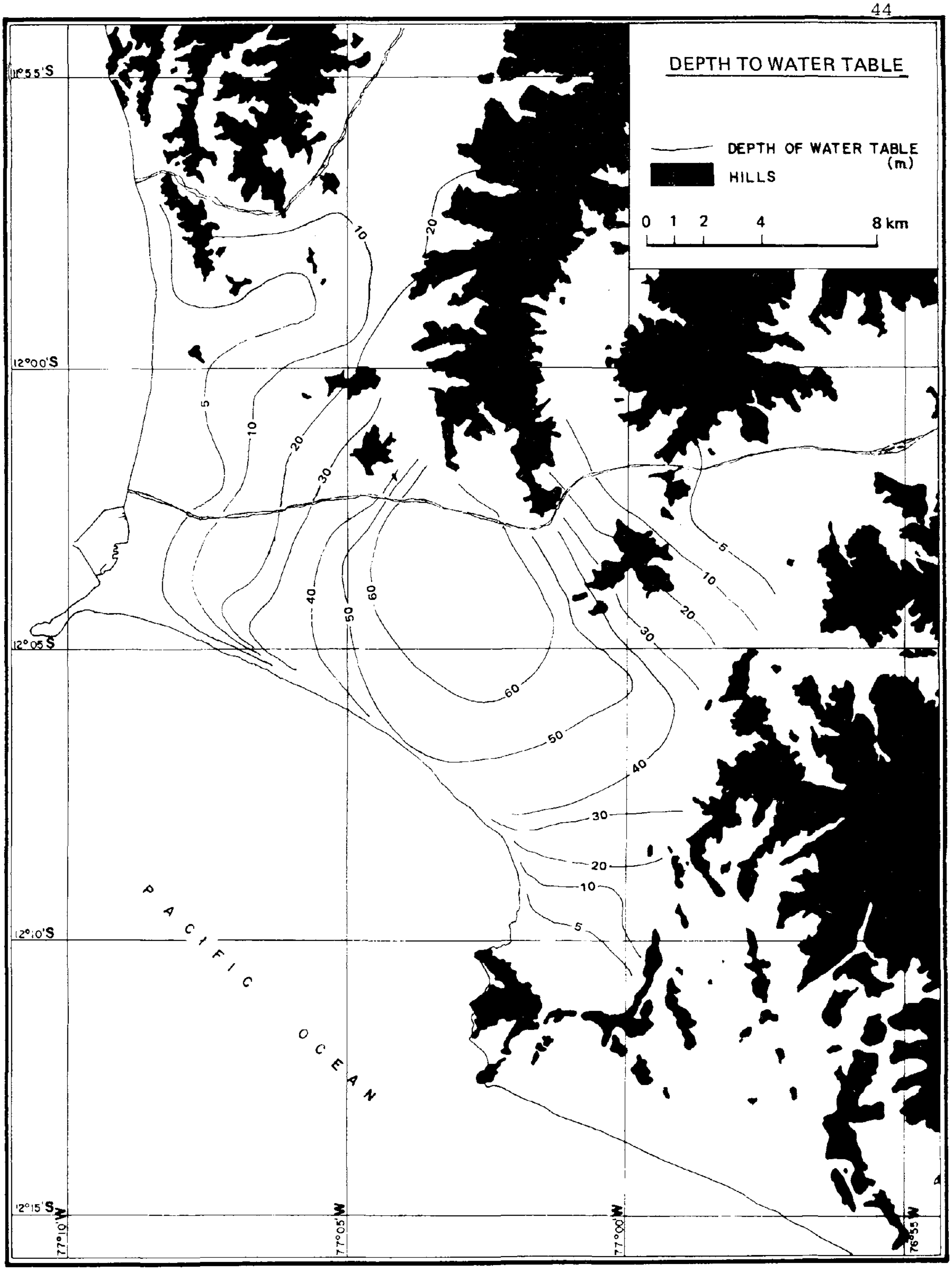


Fig. 12 – DEPTH TO WATER TABLE, GREATER LIMA

It became clear during the investigation and from the data shown in Figure 10, that the dominant subsurface material in Lima is apparently the cascajo formation and that an important key to the determination of earthquake damage to engineered structures is whether a site is underlain by cascajo or by other materials. While in some areas, such as central greater Lima, cascajo extends from base rock to within 0.5 m from the ground surface, in others such as La Molina, the cascajo either does not exist or is deeper than 30 m; at El Callao - La Punta it is 10 to 30 m or more in depth; and at La Campina (Chorrillos) it is practically nonexistent. Clearly, the areas of greater Lima, where the concentrations of structural damage were identified (Figure 7), correspond with the areas where the cascajo is underlying 30 or more meters of finer sediments. Thus, the higher damage incidence in these areas may well be attributed to the differences in the response of cascajo, compared to the other sediments, during the earthquake shaking.

To clarify the seismic response characteristics of the cascajo formation, it was decided to carry out geophysical field tests to measure the compression and shear wave velocities of the soils in Lima at a few selected locations. The shear wave velocity of a material is related to its modulus of rigidity, or stiffness, and as such is a valuable indicator of the behavior of the material under earthquake ground motions. The geophysical work and the results obtained are presented in the following section of the report.

WAVE VELOCITIES OF SUBSURFACE MATERIALS

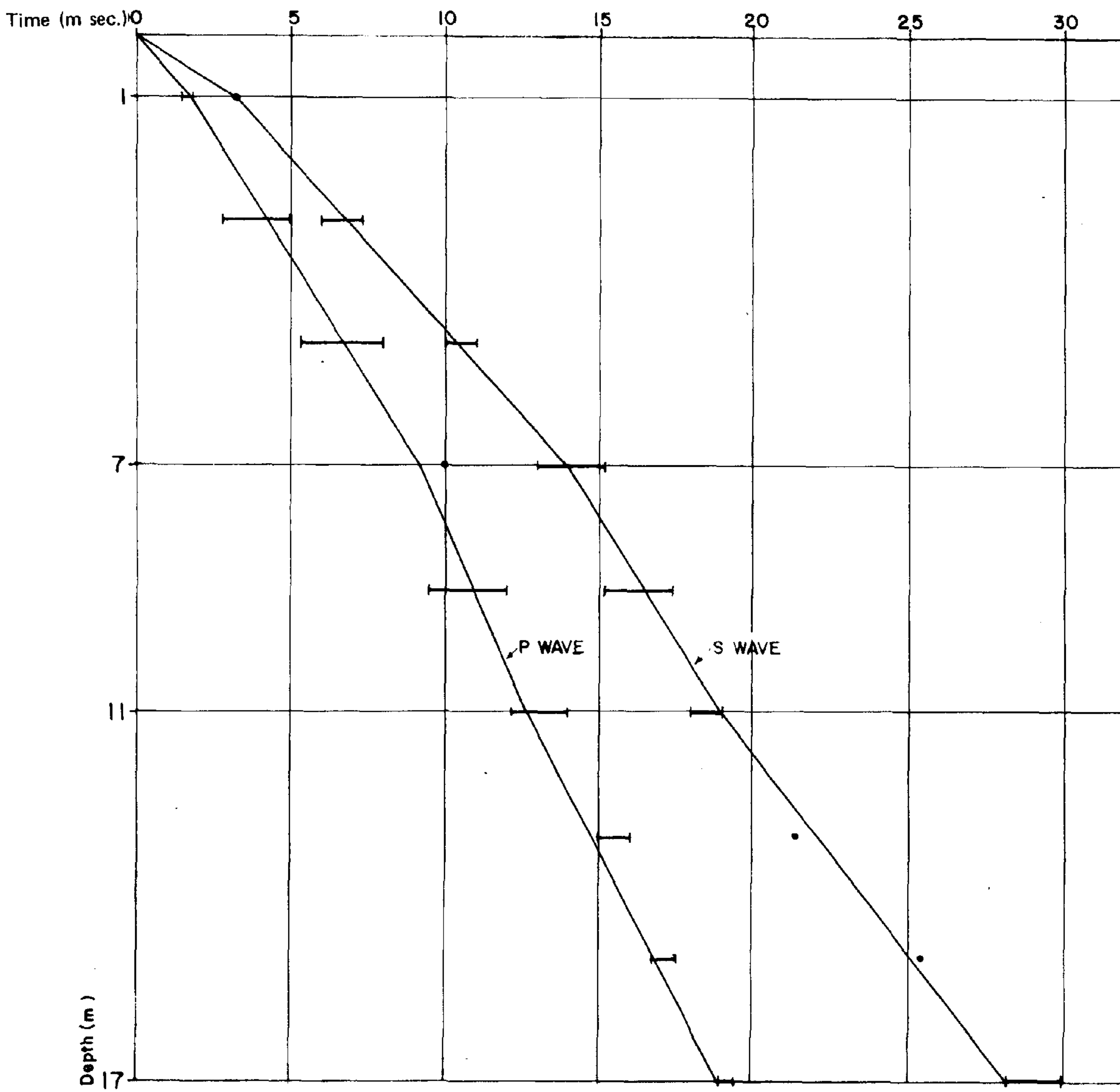
Compression and shear wave velocities were determined in the field by the downhole geophysical testing method. The following three locations (see Figure 9) were selected for testing:

- Test Site No. 1, in Parque de la Reserva, where the cascajo extends from near the ground surface to rock. This site is located about 30 m away from Lima's Geophysical Institute.
- Test Site No. 2, in Zarate, where the alluvial fans of the Rimac River and Canto Grande Creek meet. This site is located 20 m from the place where the Zarate strong motion instrument was installed.
- Test Site No. 3, in La Molina, in an area underlain by silts and clays, within 100 m from the location of the strong ground motion instrument that recorded the November 1974 aftershock. Field testing at this location was reported by Repetto and Arango in a previous study (12).

For the cascajo, Figures 13 and 14 show an average shear wave velocity of 525 m/sec at a depth of 4 m below ground surface, increasing to 700 m/sec at depths as shallow as 6 m below the ground surface. Test results at La Molina, Figure 15, show that the shear wave velocity of the sediments overlying the cascajo increase from a value of 200 m/sec at a depth of 3 feet to 700 m/sec at a depth of about 40 m.

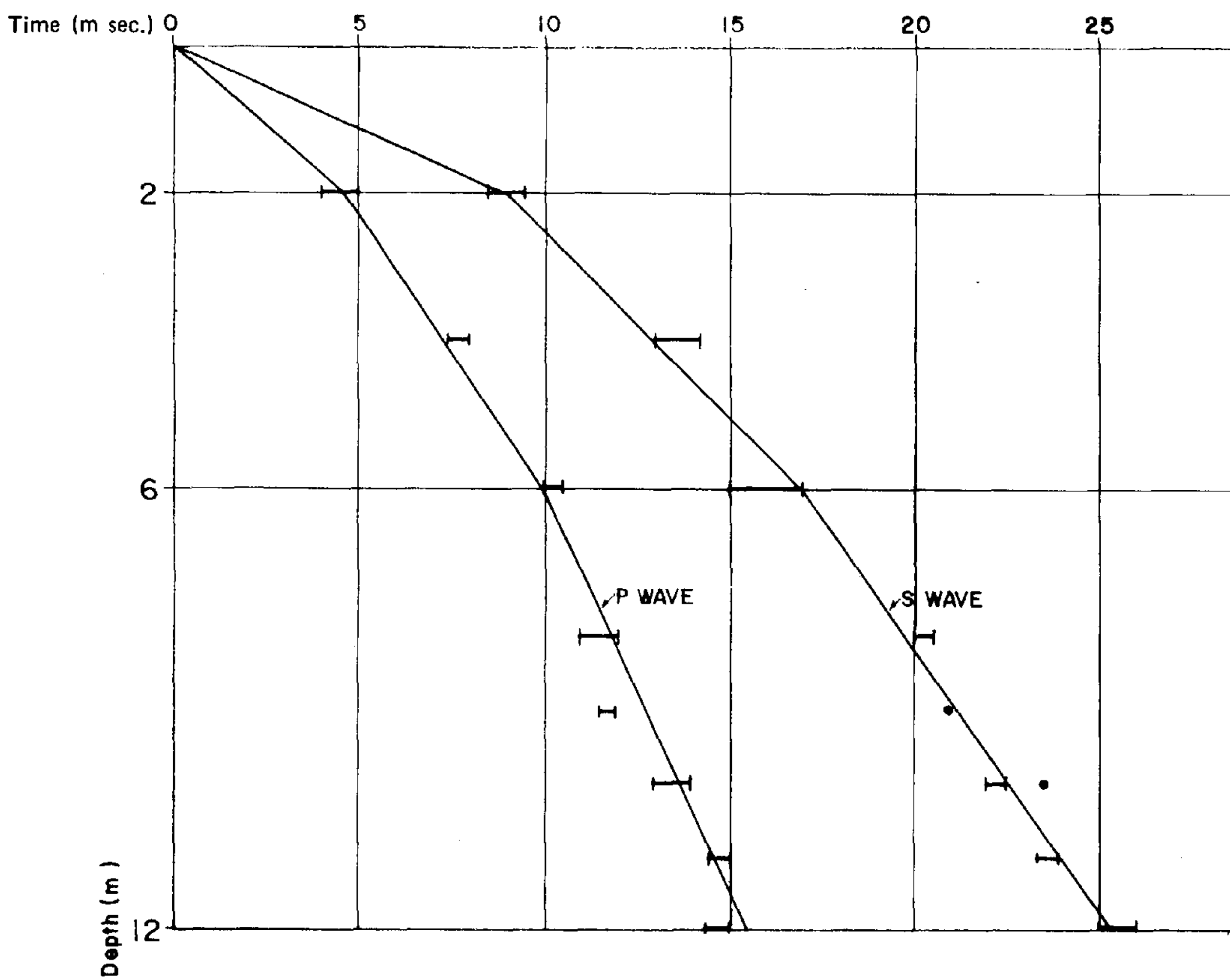
Soil profiles and standard penetration resistance values, taken at the areas of concentrated structural damage suggest that the shear wave velocity of the sediments at La Campina may be expected to be about the same as those at La Molina, and that the sediments near Callao would probably show somewhat lower values than at La Molina. Clearly, there is a pronounced velocity contrast between these three areas and the zone underlain by the cascajo. This is readily apparent in the generalized soil profiles presented in Figure 10.

Thus there is good evidence to indicate that the pattern of damage in Lima in the earthquake of October 3, 1974, is related to differences in soil



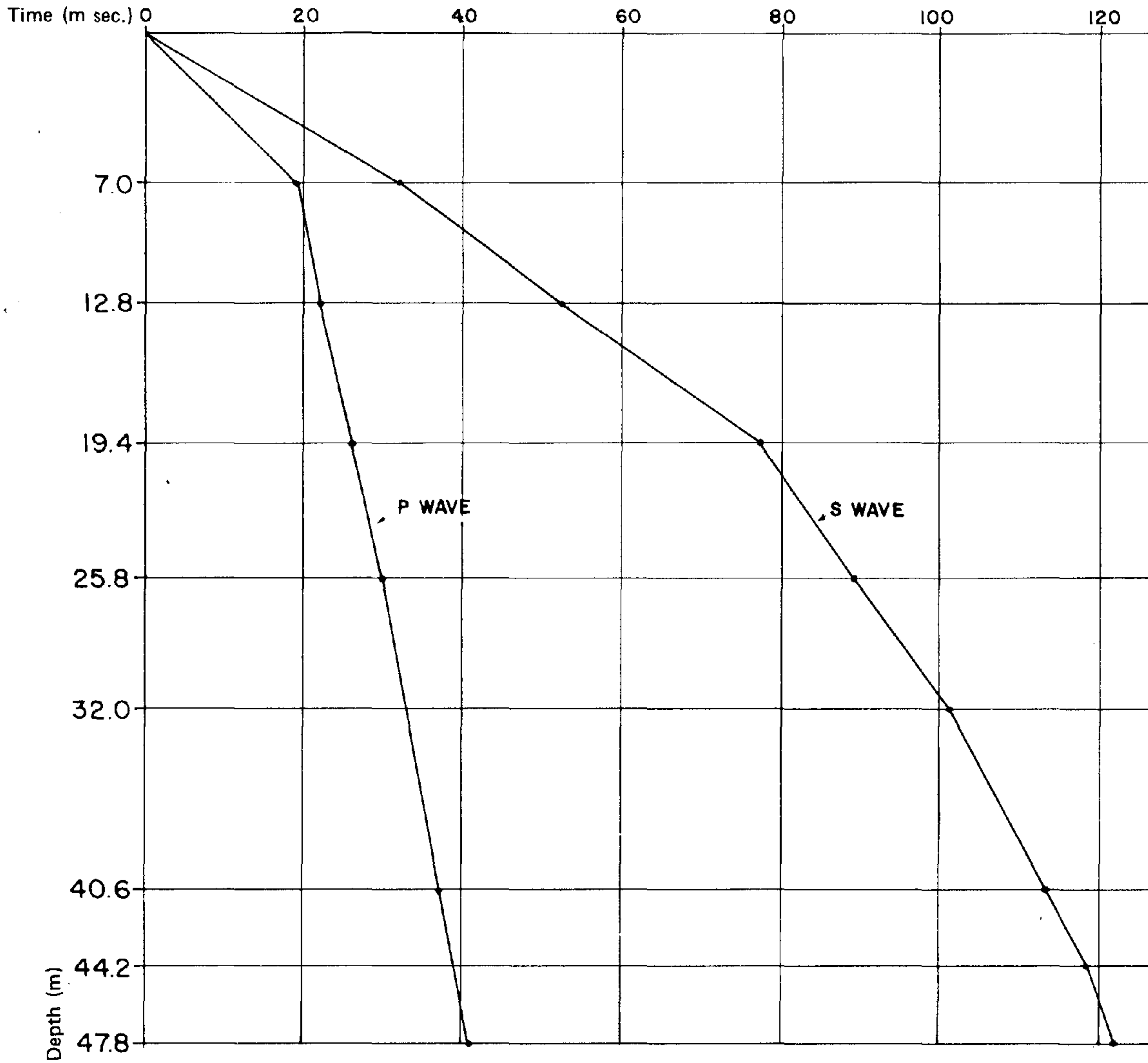
Vp (m/s)	Vs (m/s)	Vp/Vs	ν
556	323	1.722	.25
800	550	1.453	.05
1,176	800	1.471	.07
952	645	1.476	.08

Fig. 13 – DOWN-HOLE MEASUREMENT – PARQUE DE LA RESERVA



Vp (m/s)	Vs (m/s)	Vp/Vs	ν
426	222	1.915	.31
755	500	1.509	.11
1,053	706	1.491	.09

Fig. 14 – DOWN-HOLE MEASUREMENT – ZARATE



Vp (m/s)	Vs (m/s)	Vp/ Vs	ν
368	219	1.680	.23
2000	300	6.667	.49
1,600	256	6.250	.49
1,625	542	2.998	.44
2,100	508	4.134	.47
2,100	717	2.929	.43
2,400	740	3.243	.45
2,400	1,167	2.057	.345

Fig. 15 – DOWN-HOLE MEASUREMENT – LA MOLINA

conditions throughout the city and particularly to the response of the cascajo in the region. A very limited number of structures (much less than 1 percent), other than adobe-type construction, were found to have damage intensities, I_d, equal to or greater than four in the areas underlain by cascajo. The proportion of damaged structures ($I_d \geq 4$) having a similar type of construction in other areas such as Callao - La Punta, La Molina and La Campina (Chorrillos), which are underlain by stiff but not rock-like soil conditions, were found to be 4, 30, and 50 percent, respectively. These differences in response for the soils in Lima follow the patterns observed in other earthquakes, e.g., in Japan (6), Yugoslavia (9), Caracas (10) and San Fernando, California where damage intensities for 1 to 4 story structures on stiff or shallow soil deposits have also been found to be greater than those for similar structures located on rock or rock-like formations.

It has only been in the last 20 years or so that strong ground motion instrumental records have been obtained at a number of locations in the same general area to show the major effects of variations in local soil conditions on the characteristics of strong ground motions. Using recorded motions as a basis for the analysis, studies show that significant variations due to subsurface conditions may occur in the peak values of the ground motions, as well as in their frequency contents (response spectra).

The importance of response spectra as a means of characterizing the ground motions produced by earthquakes and their effects on structures has long been recognized by engineers and seismologists (3). In recognition of the importance of response spectra for structural design purposes, representative spectral shapes have been developed based on spectra from motions recorded on different soil conditions. One of the most commonly-used sets of spectral shapes is that developed by Seed et al. in 1974 and shown in Figure 16 (11).

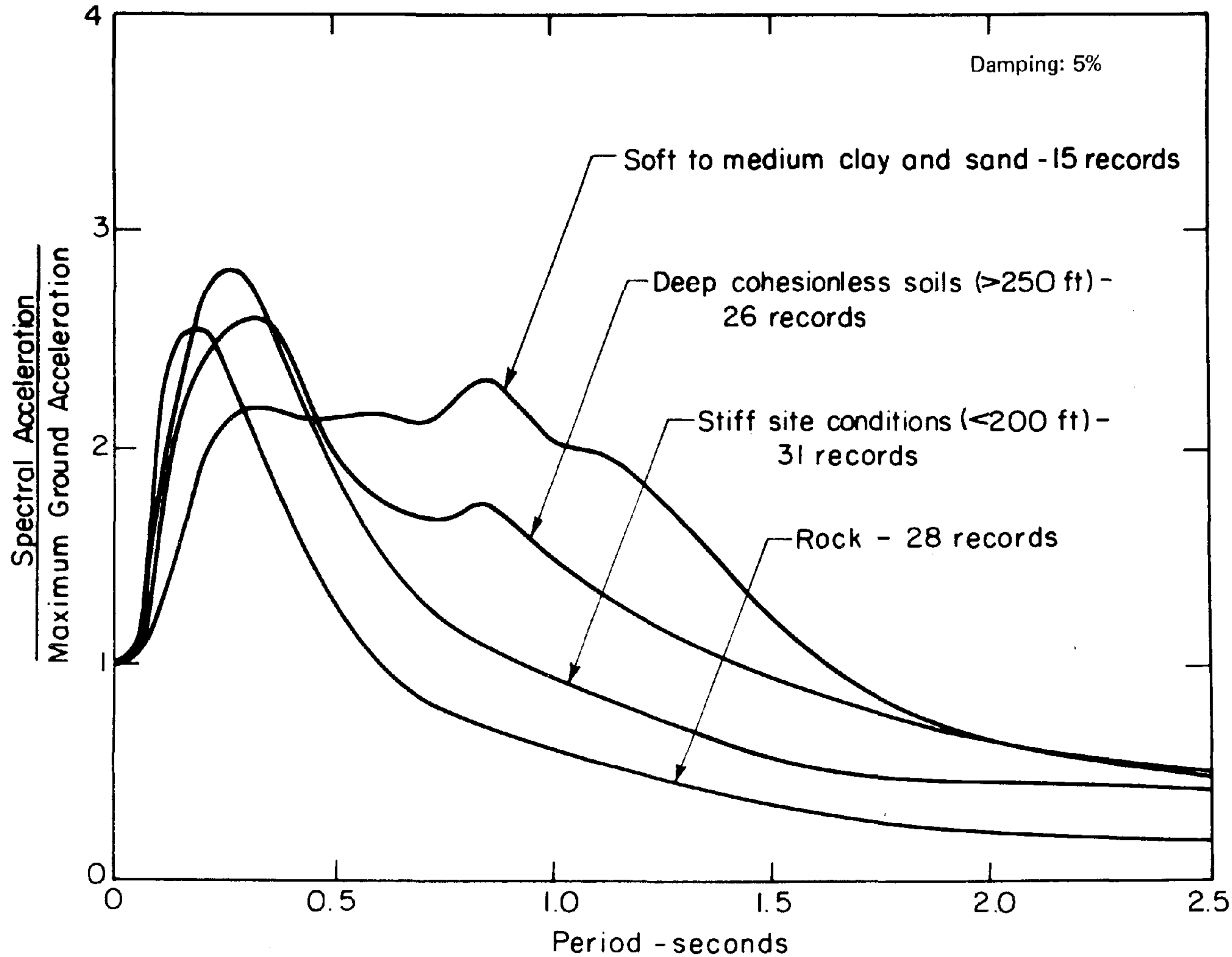


Fig. 16 — AVERAGE ACCELERATION SPECTRAL SHAPES FOR DIFFERENT SITE CONDITIONS
(Seed, Ugas, Lysmer, 1974)

With the availability of records from the October 1974 earthquake, the November aftershock, and other previously recorded events in Lima, it appears possible to explore the relationship between the general characteristics of recorded spectral shapes and the local soil conditions at the recording stations. The results of such an investigation are presented in the following section.

SPECTRAL CHARACTERISTICS OF PERUVIAN EARTHQUAKES

Preliminary calculations dating back to 1971 (13) pointed out certain important characteristics of a few earthquakes originating in the subduction zone opposite the Peruvian Pacific Coast. These characteristics include the high frequency content of the records, the rather large peak ground accelerations recorded at considerable epicentral distances, and the long duration of the strong motions. Only recently (1977), however, have several records been digitized and made available for detailed study (1).

A total of ten recordings in Lima, each providing three components of ground motion produced by seven separate events are now available. Two records were obtained during the October 3, 1974, earthquake and another two during the aftershock that followed on November 9, 1974. The other records were obtained during earthquakes in 1951, 1966, 1970, 1971, and January 1974.

Recordings have been obtained at four locations within the greater Lima area: (1) the Geologic Institute at Plaza Habich and the Geophysical Institute, Parque de la Reserva, both in downtown Lima, (2) the Zarate station (dismantled after the Jan. 1974 earthquake), in the San Juan de Lurigancho district; (3) the La Molina station, at the campus of the

Universidad Nacional Agraria; and (4) the residence of Dr. Huaco, at the Gardenias Housing Development, southeast of downtown Lima.

Soil subsurface conditions at the locations of these stations have also been determined. The Geophysical Institute is located in the downtown area which is underlain by cascajo, and which at this point extends from the ground surface to rock. Shear and compressional wave velocities were measured at a location 20 m away from the recording station, Figures 9 and 13. At this location, rock-like shear wave velocities of the order of 700 m/sec were obtained 6 m below the ground surface. Similar subsurface conditions exist at the Geologic Institute and Dr. Huaco's residence; hence similar velocities are expected to occur at these locations.

The Zarate boring log (Figure 10) and the wave velocities from Figure 14, were obtained 20 m away from the site formerly occupied by the dismantled Zarate station. Again, rock-like velocities were measured beginning at 6 m below the ground surface.

Soil Profile 5, in La Molina (see Figure 10), and the velocities tabulated in Figure 15, were obtained a short distance from the place where the November aftershock was recorded in La Molina. At this location, the sediments from the ground surface to a depth of about 30 m are stiff silts and clays, with shear wave velocities ranging between 200 m/sec and 500 m/sec. Rock-like velocities were measured at depths of about 32 m below ground surface, and deeper.

Data regarding the strong ground motion recordings obtained at these stations are presented in Table 14. The limited number of records does not permit a detailed statistical analysis. However, an attempt has been made to detect general trends in the data, and to compare them with data

TABLE 14. STRONG GROUND MOTION DATA

Record No.	Date	Earthquake Magnitude M_S	Focal Depth - km	Recording Station	Epicentral Distance (Km)	Hor. Accel. g's
1	01/31/51	-	-	Geol. Inst.	105	0.07; 0.06
2	10/17/66	7.5	24	Geophys. Inst.	236	0.27; 0.40
3	05/31/70	7.8	43	Geophys. Inst.	372	0.12; 0.13
4	11/29/71	5.3	54	Geophys. Inst.	127	0.06; 0.06
5	01/05/74	6.5	98	Geophys. Inst.	74	0.09; 0.11
6	01/05/74	6.5	98	Zarate	73	0.14; 0.16
7	10/03/74	7.5	13	Geophys. Inst.	86	0.25; 0.21
8	10/03/74	7.5	13	Huaco Residence	91	0.20; 0.25
9	11/09/74	7.0	6	Geophys. Inst.	95	0.03; 0.08
10	11/09/74	7.0	6	La Molina	103	0.11; 0.14

and trends from recordings obtained in other parts of the world. For this analysis, the recordings obtained at the Geophysical and Geological Institutes, and the Zarate and Huaco stations were analyzed as a group, since they all share similar subsurface conditions (cascajo with rock-like velocities near the surface). The two ground motion components obtained at La Molina were analyzed as a second group representative of soil deposits in the area.

Normalized acceleration response spectra were first determined from all the motions in each group, and these were then averaged to obtain the mean spectral shapes, which are presented in Figure 17. It is readily apparent that there is a difference in spectral shapes depending on site conditions, particularly for periods between about 0.15 seconds and 1.5 seconds. Above 0.15 seconds, the spectral accelerations are much higher for the stiff soil conditions at La Molina than for the rock-like velocity material, cascajo.

The representative site-dependent spectral shapes for rock and stiff soil conditions from Figure 16 are plotted with the Lima average spectra in Figure 18. In spite of the different sources of the readings, there is a good agreement between the spectral shapes obtained from the two independent data sets up to periods of about 1.25 seconds. For periods greater than about 1.5 seconds, the spectral accelerations for the Peruvian earthquakes are lower than the corresponding spectral values proposed by Seed and others. The Peruvian spectra were derived from motions generated by earthquakes on subduction zones, while the shapes proposed by Seed et al. were primarily based on data from continental earthquakes. Studies by Idriss (5) indicate that records from subduction zone earthquakes are generally deficient in long period waves, thus corroborating the

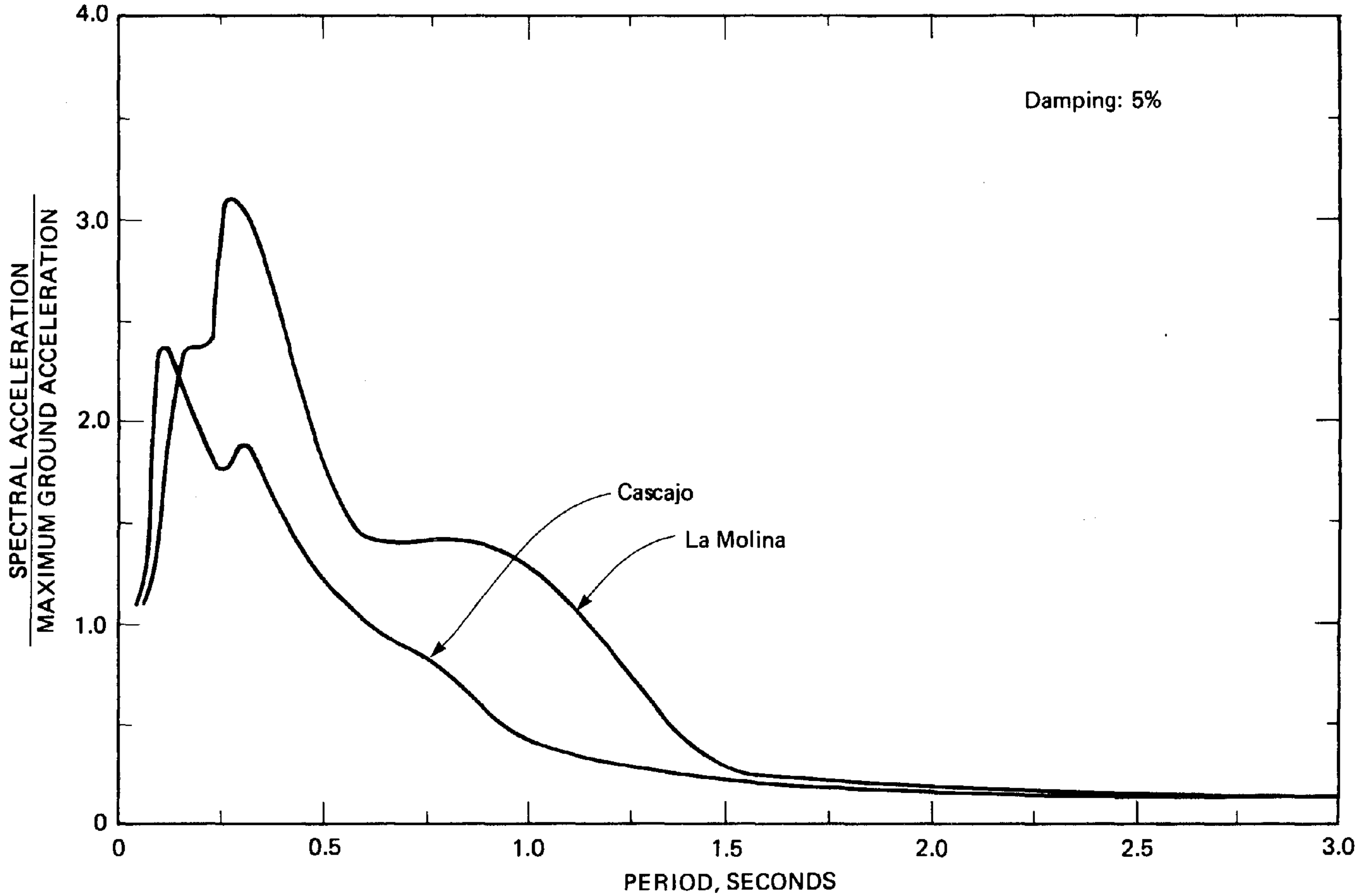
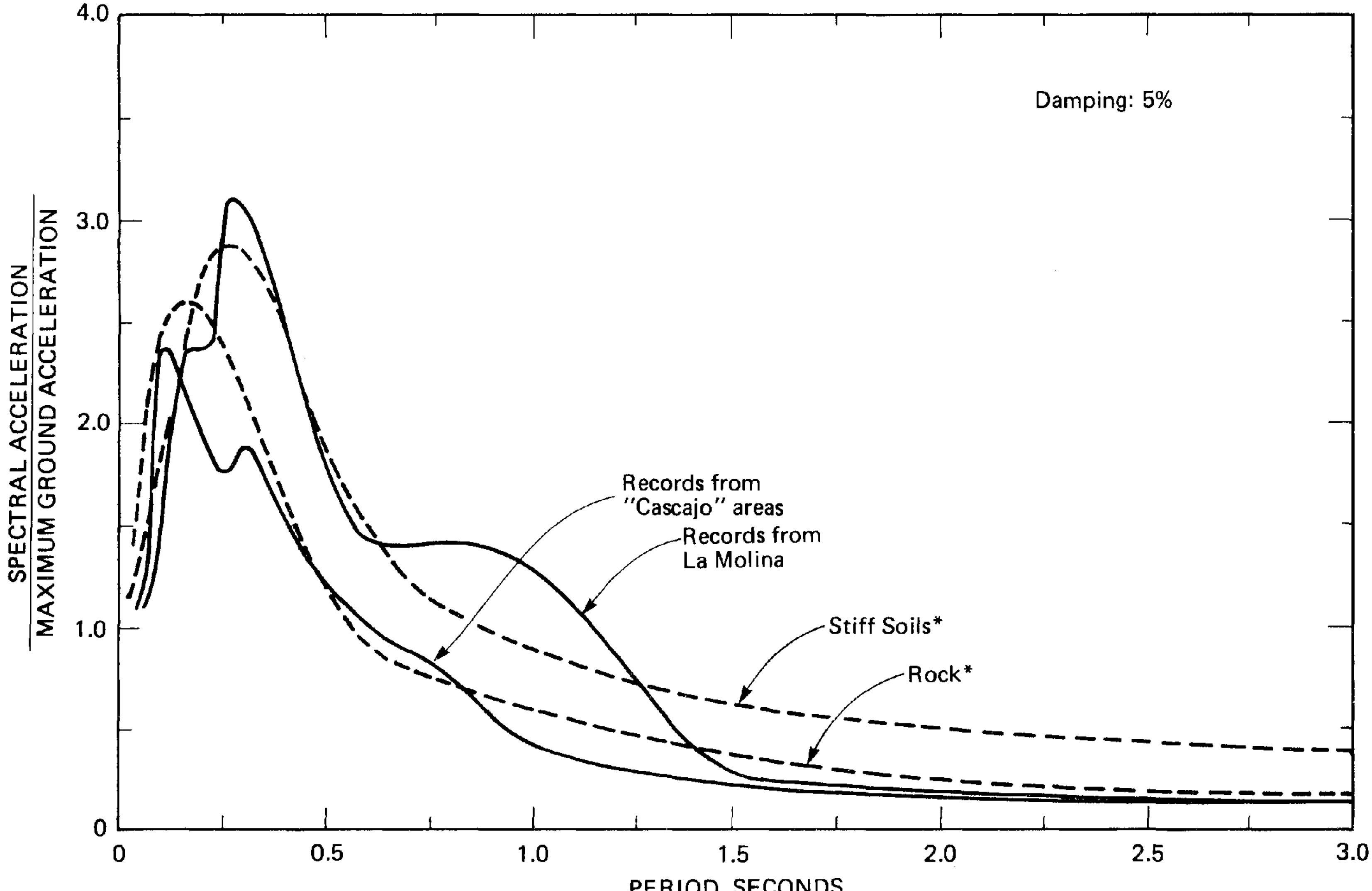


Fig. 17 – AVERAGE ACCELERATION SPECTRAL SHAPES FOR DIFFERENT SOIL CONDITIONS, GREATER LIMA



*Seed, Ugas, Lysmer (1974)

Fig. 18 – COMPARISON OF AVERAGE SPECTRAL SHAPES FOR LIMA SOILS AND FOR SOILS FROM OTHER AREAS

relative values shown in Figure 18 at the long period end of the spectra.

In order to compare representative response spectra for areas underlain by cascajo with those underlain by stiff soils as in La Molina it is also necessary to determine any significant differences in peak ground acceleration in these areas. It may be noted that in the November 9, 1974, earthquake which was reasonably comparable to the October 3, 1974 event but produced somewhat lower shaking intensities, the average peak acceleration recorded at La Molina was about 100% higher than the average recorded on cascajo at the Geophysical Institute (see Table 14). While this difference is likely to decrease as the intensity of shaking increases it is not unreasonable to expect that in the October 3, 1974 earthquake, maximum ground accelerations on stiff soil sites such as La Molina would be of the order of 30% higher than those on sites underlain by cascajo. Thus since the maximum ground accelerations on cascajo in this event was about 0.23g (average for 4 recordings), the maximum ground acceleration in areas on stiff soil such as La Molina is likely to have been about 0.30g. Using these values as zero period values for the representative spectral shapes shown in Figure 17, it may be anticipated that representative spectra for different site conditions in the October 3, 1974 earthquake would be similar to those shown in Figure 19.

The relative values of the spectral amplitudes of the mean spectra for the different areas of Lima shown in Figure 19, explain why low period, 1 to 4 story structures, such as the brick-bearing wall and R.C. frame dwellings which are so prevalent in the city of Lima, perform better in the areas of the city underlain by cascajo than in areas such as Molina with generally deeper but stiff soil conditions. In an undamaged condition,

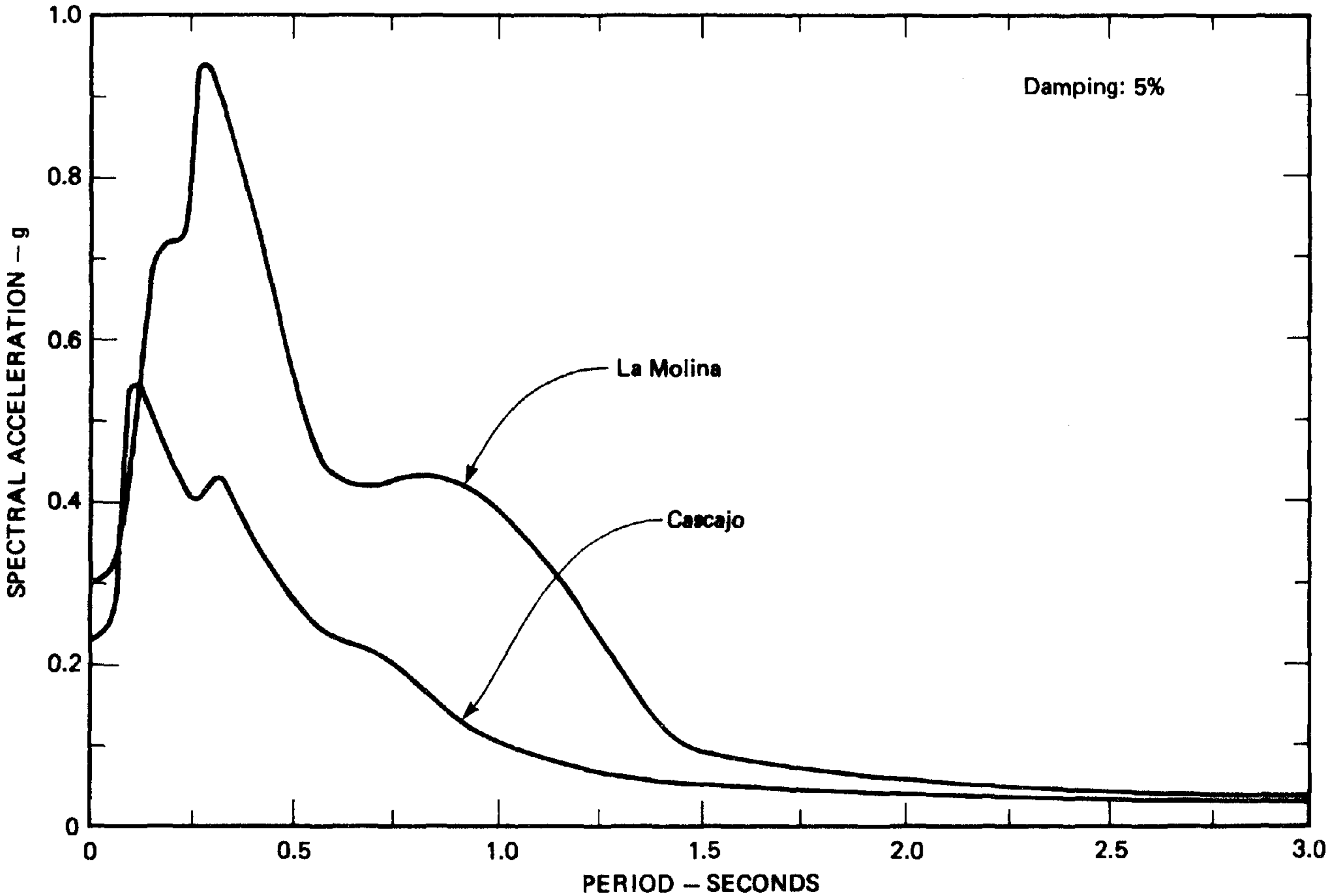


Fig. 19 – PROBABLE REPRESENTATIVE ACCELERATION SPECTRA FOR DIFFERENT SOIL CONDITIONS IN GREATER LIMA – OCT. 3, 1974 EARTHQUAKE

1 story structures with periods of the order of 0.10 second may be expected to have approximately the same dynamic response in all areas. However, once cracking of such a structure begins to develop, causing the structural period to increase to values, say 50 to 100 percent larger than its original value, the force developed on a structure constructed on a stiff soil deposit would be almost twice that for a similar structure located on a cascajo site. For 2 to 4 story structures, the response on stiff soil sites such as La Molina would be about twice that for similar structures on cascajo, even without cracking. As shown in Figure 9, most of metropolitan Lima is founded on the area underlain by the cascajo formation. It is not surprising, therefore, that damage due to earthquakes in this city is not so severe as the damage observed in other cities where subsurface conditions are closer to those encountered outside the cascajo area of Lima. It is also understandable why damage to buildings on the stiff soil areas of La Molina, Callao and Chorillos would be greater in the earthquake of October 4, 1974, than in the main part of the city of Lima.

CONCLUSIONS

The preceding pages present the results of a study of the effect of site-dependent factors on the damage observed in Lima during the 1974 and previous earthquakes. In the course of the study, it was found that damage to adobe and quincha construction, due to its poor resistance characteristics, cannot be taken as an indicator of the severity of the earthquake ground motion in different areas of the city. However, a good correlation was found between damage to better built brick-bearing wall and R.C. frame buildings and the subsurface conditions. The areas of largest damage concentration and highest damage intensities were associated with areas underlain by thicker sediments overlying rock-like material. On the other hand, the characteristics of the cascajo formation, which overlies most of the city, are such that its earthquake response resembles that of softer rock, which imposes lower dynamic loads on structures founded on it, especially for structures with periods typical of those in the greater Lima area.

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