Ground Shaking

Ground shaking is by far the most important earthquake induced geologic hazard in the metropolitan area of San Juan. It is caused by the sudden release of elastic strain energy stored in the rocks. This process (faulting) generates different waves that propagate from the rupture zone. Two classes of waves are generated: body and surface waves.

Body waves consist of compressional (P) and shear (S) waves. They traverse the Earth's interior with different velocities and motions. Surface waves are Love and Rayleigh waves that travel more slowly than body waves. Body waves are mainly high frequency vibrations that are likely to make low buildings resonate. Surface waves cause mainly low frequency vibrations more efficient in making tall buildings vibrate. When buildings cannot resist earthquake vibrations generated by these waves, damage occurs (Hayes, 1981).

It has long been recognized that different locations at essentially the same epicentral distance experience large variations in the distribution of damage due to the influence of local geologic and soil conditions on ground motion. Soil conditions such as thickness, water content, physical properties of the unconsolidated material, bedrock topography, geometry of the unconsolidated deposits and underlying rock, among others, can modify the ground surface motions by changing the amplitude and frequency content of the motion. Amplification of ground motion in a period range that coincides with the natural period of vibration of the structure explains the distribution of damage (Hays , 1980). Shorter period waves oscillate in the same frenquency range as lower buildings, affecting such structures close to the epicenter. Longer period waves, which oscillate in the same frequency range as taller buildings, travel farther and can affect such buildings at relatively great distances from the epicenter. This is a potentially serious hazard in the metropolitan area of San Juan because tall buildings can resonate with higher period waves generated by relatively distant earthquakes offshore.

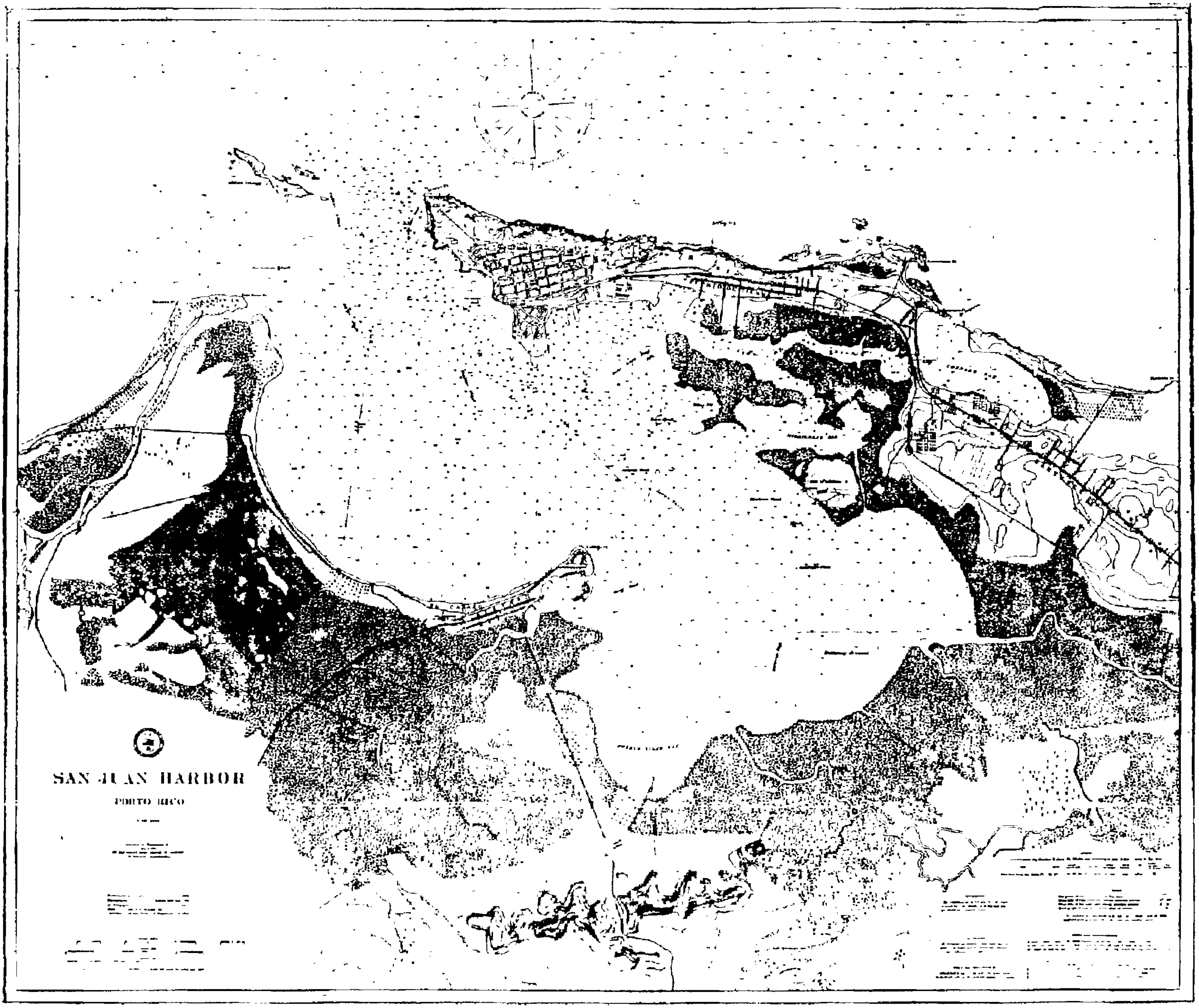
Local soil conditions modify the seismic input by generating maximum accelerations at lower periods for stiff soils where short height structures are likely to suffer more damage. In soft soils maximum accelerations occur at higher periods where taller structures are subjected to the worst conditions.

In general, areas underlaid by thick deposits of uncompacted artificial fill, by soft, water saturated mud, or by unconsolidated stream sediment shake longer and harder than areas underlaid by bedrock (Brown and Kockelman, 1983). During the October 11, 1918 earthquake, the La Playa sector of Ponce was more severely shaken than the higher part of the city. Humacao suffered far more than other towns in the same area because it was built upon the alluvium. The greatest damage was registered in Aguada and Añasco, both located on alluvial deposits, while Rincón, built on bedrock and closer to the epicenter than Añasco, suffered much less damage (Reid and Taber, 1919).

Three main deposits are mapped in terms of ground shaking hazard. The lowest hazard is assigned to rock outcrops, high terrace, alluvial fan, older alluvial, and blanket deposits. Rock outcrops include Cretaceous and Early, Terciary volcanic and sedimentary rocks; Middle Terciary formations such as Cibao, Aumamon, Aguada and San Sebastian, and eolianites. The rest are semiconsolidated deposits of Pleistocene and Miocene age characterized by being stiff, hard, and compact. Depth ranges from less than 10 meters in Carolina to more than 100 meters in San Juan and less than 50 meters in Bayamón (Monroe, 1973, 1977; Pease and Monroe, 1977). Diagenesis has resulted in a material that behaves much like bedrock.

All zones of moderate to high ground shaking hazard include all alluvial deposits of Holocene age and some terrace deposits of Pleistocene age. The deposits are present in the floodplains of Río Bayamón, Río Piedras, and Río Grande de Loíza. In Carolina the sand, clay, and sandy clay beds are up to 100 meters thick. Beds of sand, clay, and sandy clay exceed 20 meters in San Juan and Bayamón. These zones are much more vulnerable to ground shaking than the "stiff" clays but are considered, in general, less vulnerable than artificial fills placed over swamp and lagoonal deposits.

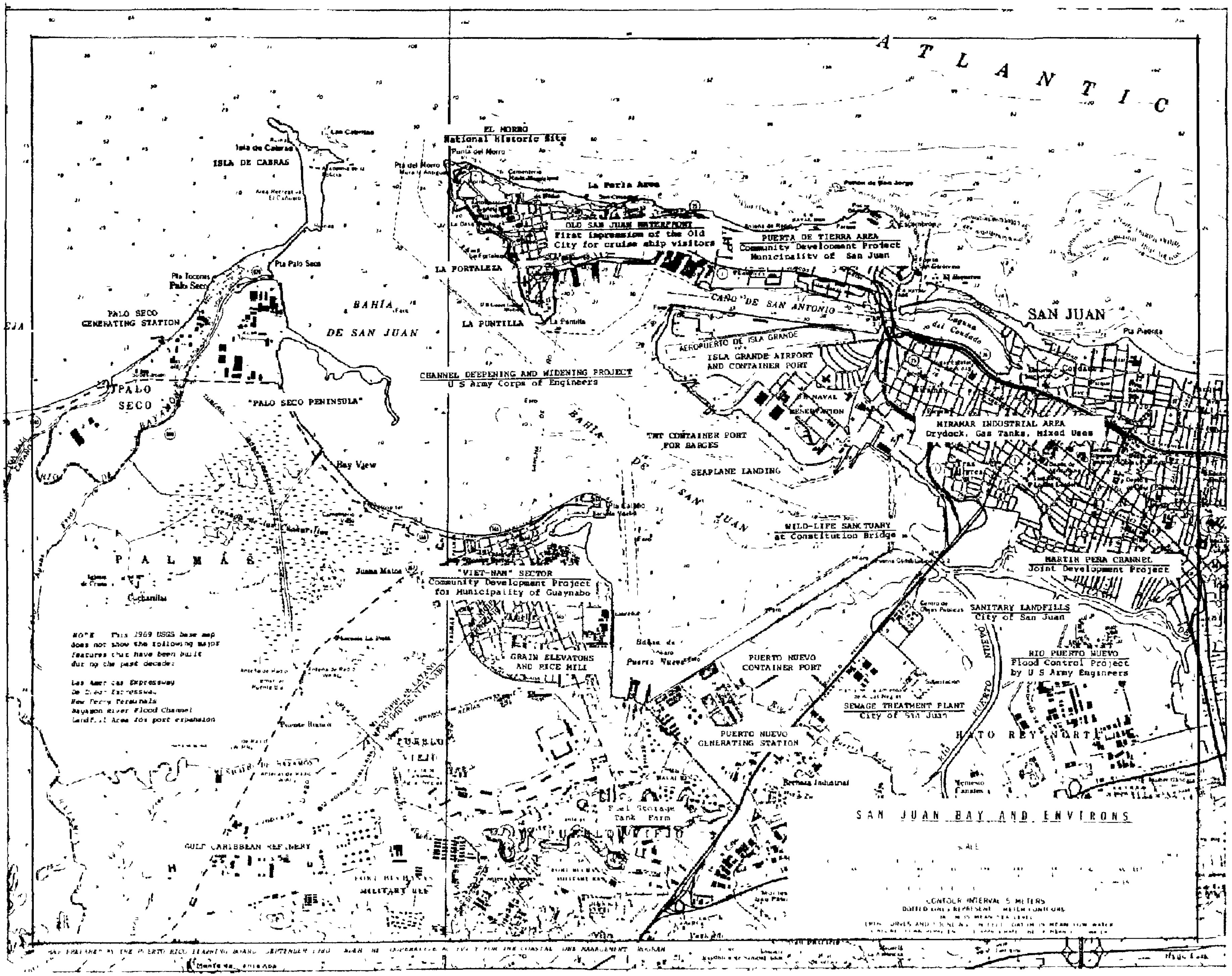
Fill materials have been shown to behave very poorly during earthquakes (Munich Re,1973). Extensive filling to mangrove swamp (Fig. 15) with fill material ranging from rock and sand, to soft, black, mucky clays dredged from the bottom of San Juan Bay after 1940, have created potentially unstable conditions. Manmade fills consisting of materials ranging from silt to sandy gravel have failed during earthquakes due to liquefaction of the basal zone of the fills themselves or in natural foundation materials underlying the fills (Keefer, 1984). In fact, flow failures carried away large sections of the port facilities at Seward, Wittier and Valdez, Alaska during the 1964 Prince William Sound Earthquake. Ground shaking induced failures caused the sinking of Port Royal in Jamaica 1692. Although the conditions where these events took place are not exactly the same as those present in San Juan Bay, the possibility of ground failure of portions of the artificial fill surrounding the Bay during a large earthquake cannot be discarded. The presence of relatively deep fill materials over swamp deposits and very high water tables place these areas under a combined high ground failure and ground shaking hazard. Ground shaking damages result



BiC-55

SAN JUAN BAY AND ENVIRONS. 1911

Fig. 15 Location of Mangrove before filling of swamps and lagoonal deposits



NOTE This 1969 USGS base map does not show the following major features that have been built during the past decade:

Las Americas Expressway
De Diego Expressway
New Ferry Terminals
Bayamon River Flood Channel
Landfill Area for port expansion

from the interaction of ground motion with the building structure. Ground motion characteristics are mainly determinaed by the depth of the focus, its magnitude, attenuation, and local ground response. The most important of these factors have been discussed earlier in this report. Building damageability depends mainly on the building ordinances and their effectiveness, design and construction technology, type of building structure, and location.

In Puerto Rico, building regulations containing lateral force provisions for earthquake went into effect in September, 1954. Prior to that date buildings were constructed using individual standards selected by each builder; but a building code alone is no garranty of an adequate building performance during an earthquake. Other factors such as the experience of the designers, material quality, quality of workmanship, and supervision affect damageability. Steinbrugge (1962), during an inspection of several buildings in the metropolitan area of San Juan, found that in many buildings earthquake provisions and workmanship requirements were not effectively policed by the Puerto Rico Planning Board. Design errors and poor workmanship were commonly found even in the larger buildings.

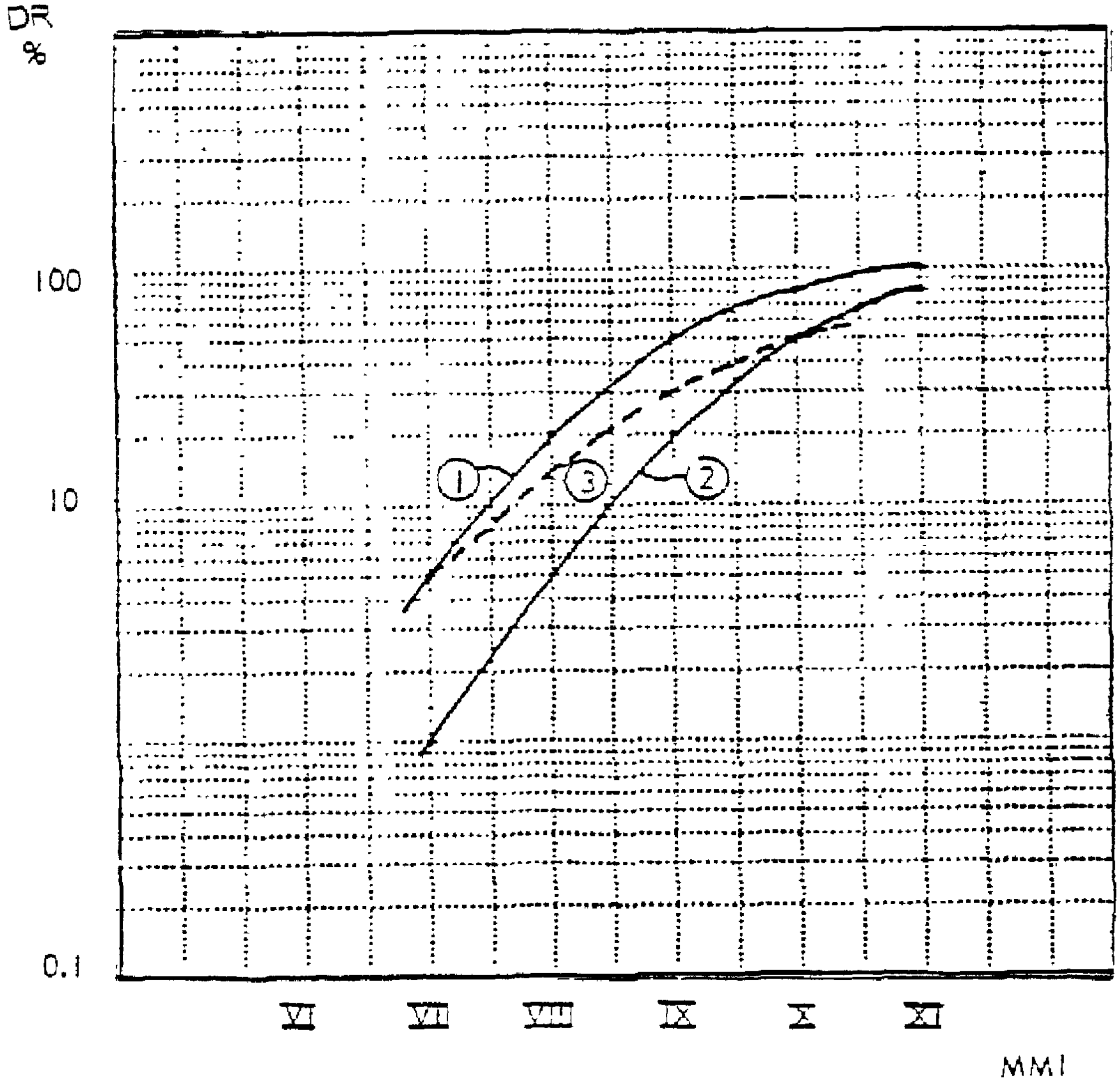
Today, potentially serious deficiences are present in the actual building code. Leandro Rodríguez (1984) emphasizes that the present building code does not consider ductility, does not address soil structure interaction, does not consider the importance of the structure (for example the same design criteria are used for hospital and for a one-family house), and does not recommend earthquake resistant designs for underground lifeline structures. Thus, in spite of the building regulations, a significant number of structures in the metropolitan area are not likely to resist earthquake loadings adequately. Fortunately, the Seismic Committee of the Colegio de Ingenieros, Arquitectos y Agrimesores has submitted to the Puerto Rican Building Permits and Regulation Administration an updated proposal for the design of earthquake resistant structures in Puerto Rico.

Damage assesment of ground shaking hazard follows the procedures recommended by Rice (1983). Most of the information presented below originates from this source. The methodology considers only damage to buildings. Other facilities such as plants, dams, lifelines, etc., are outside its scope. Damage assesment is obtained by overlaying a building inventory map on the hazard map.

The structure response for different types of buildings,ground motion, and soil condition is based on past earthquake experience. The predicted damage is expressed as percent loss or damage ratio. This widely used parameter represents the ratio of the cost of repair to the replacement cost. For individual buildings, damage ratios beyond .5 are considered total losses. Since damage ratios of .3 already correspond to severe damage states, damage ratios typically vary from 0 to .3, increasingly rapidly to 1. The damage ratio for different building types are presented in fig. 16 and 17.

The dominant type of building structure in the metropolitan area of San Juan is shear wall with seismic design (estructuras a base de muros de corte con diseño sísmico) . Damage ratios for other types of structures are shown in fig. 17. Areas of low ground shaking amplification (B-1) correspond to a MMl of VIII. In areas with moderate to very high ground motion amplification (B-2), damage ratios were raised .75 intensity (MMI). In areas with high ground motion amplification (B-3) damage ratios were raised 1.0 intensity (MMI). Damage ratios for ground shaking, liquefaction and landslides are shown in table 3.

AVERAGE DAMAGEABILITY FOR "MODERN CONSTRUCTION"
TAKEN FROM SAUTER AND SHAH, 1978;
ORIGINALLY FROM "GUATEMALA 1976-EARTHQUAKE OF THE
CARIBBEAN PLANT", MÜNCHENER RÜCKVERSICHERUNGS-
GESELLSCHAFT, MUNICH



1 Modern construction. No seismic design

2 Modern construction. Seismic design

3 Average damage ratio used by Münchener Rückversicherungs-Gesellschaft (verbally communicated to Sauter and Shah, 1978)

Fig. 16

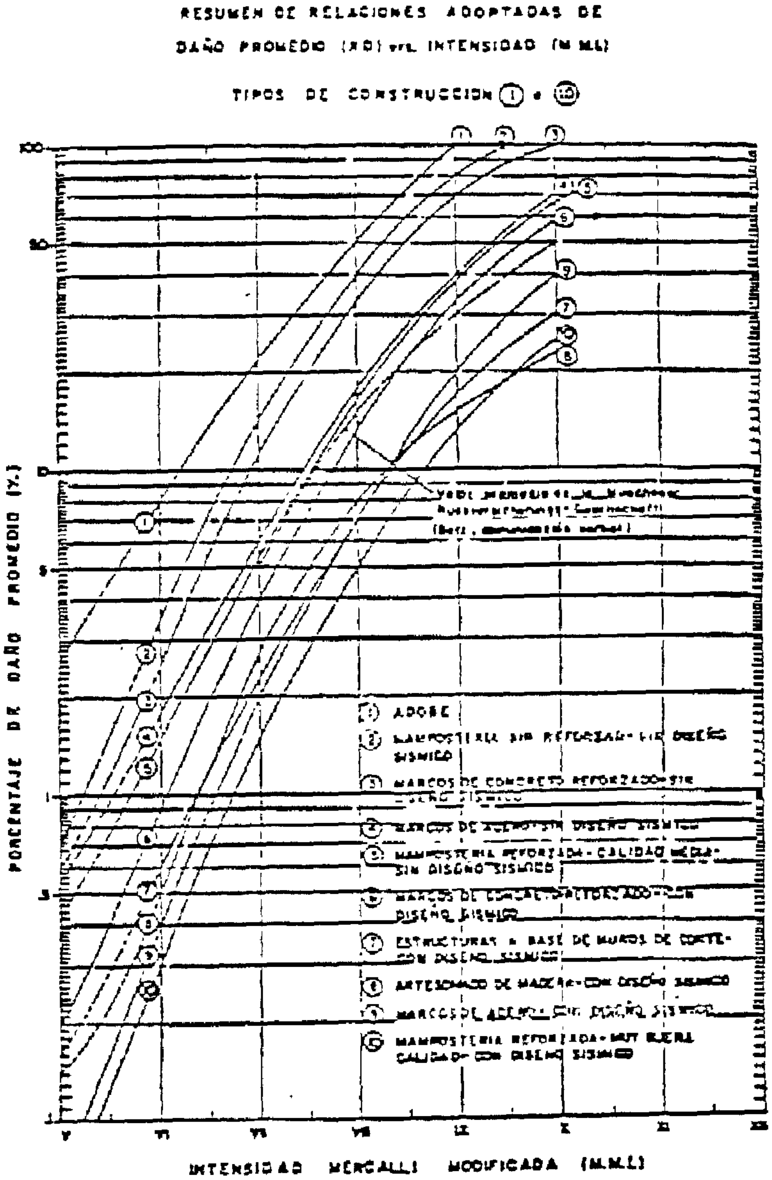

RESUMEN DE RELACIONES ADOPTADAS DE
DAÑO PROMEDIO (% D) vs. INTENSIDAD (M.M.I.)
TIPOS DE CONSTRUCCION ① a ⑩
100
50
10
5
1
.5
.1
PORCENTAJE DE DAÑO PROMEDIO (%)
V
VI
VII
VIII
IX
X
XI
XII
INTENSIDAD MERCALLI MODIFICADA (M.M.I.)
① ADOBE
② MAMPOSTERIA SIN REFORZAR - SIN DISEÑO SISMICO
③ MARCOS DE CONCRETO REFORZADO - SIN DISEÑO SISMICO
④ MARCOS DE ACERO - SIN DISEÑO SISMICO
⑤ MAMPOSTERIA REFORZADA - CALIDAD MEDIA - SIN DISEÑO SISMICO
⑥ MARCOS DE CONCRETO REFORZADO - CON DISEÑO SISMICO
⑦ ESTRUCTURAS A BASE DE MUROS DE CORTE - CON DISEÑO SISMICO
⑧ ARTESONADO DE MADERA - CON DISEÑO SISMICO
⑨ MARCOS DE ACERO - CON DISEÑO SISMICO
⑩ MAMPOSTERIA REFORZADA - MUY BUENA CALIDAD - CON DISEÑO SISMICO

Fig. 17

TABLE 3

Generalized Damage Ratio Estimates

Hazard Zone	% Area	Damage Ratio
A-1	2	.35
	98	.05
A-2	5	.35
	95	.05
A-3	10	.35
	90	.07
B-1	100	.05
B-2	90	.15
	10	.35
B-3	20	.35
	80	.20
C-1	2	.10
	98	.05
C-2	5	.10
	95	.05
C-3	15	.10
	85	.05

Hazard zones are shown in the Earthquake-Induced Geologic Hazard Map included with this study.

Damage Ratio is the ratio of the cost of repair to the cost of replacement.

$$DR = \frac{\text{Repair Cost}}{\text{Replacement Cost}}$$

Liquefaction

Although landslide is chiefly a hillside process, earthquakes can also cause ground failure in the lowland due to the process of liquefaction. When cohesionless water-saturated materials are subjected to earthquake vibrations, the tendency to compact is accompanied by an increase in pore water pressure in the soil due to load transfer from soil particles to pore water. Drainage can occur, but if restricted, pore water pressure can rise to an amount equal to the weight of the column of soil above the soil layer. Under this condition the soil may suffer great deformations and behave like a fluid rather than like a solid for a short period of time. Any structures, fills, and embankments located on liquifying soil will undergo deformations. These can be caused by lateral spreads, flow failures, and by the loss of bearing strength. In addition, ground settlement and sand boils can occur. The settlement of sand is principally caused by the horizontal shear component of motion. Lee and Albasia (1974) found that vertical settlements from drainage effects may be as much as 3% of the height of the affected soil layer. If sands are saturated, ground subsidence might be expected from soil compaction and water drainage at stresses less than required to induce complete liquefaction. The volumetric settlements from pore water pressure lower than that causing liquefaction are generally less than 1%.

Geologic conditions favoring liquefaction are: 1) a potentially liquefiable bed or lense of porous, well-sorted sand, 2) water saturation of intergranular pore spaces in the bed or lens , 3) confinement of pore water by impermeable layers above and below the liquefiable bed, and 4) proximity of the liquefiable bed to the surface (50 feet or less).

Liquefaction occurs mainly where sands and silts have been deposited during the last 10,000 years and where ground water is within 10 meters of the surface. Generally, the younger and looser the sediment and the higher the water table, the more susceptible the soil is to liquefaction. In Puerto Rico, liquefaction was observed in the lowlands of Rincón during the October 11, 1918 earthquake. Water, bringing up sand, issued from cracks. The same phenomenum was observed in Añasco, but here the water brought up black sand. Liquefaction was reported in sandy, saturated alluvial materials in areas where the earthquake intensity (Rossi-Forel) was greater than VII (Reid and Taber, 1918). Massive water drainage from alluvial soils increased stream discharge for days after the earthquake.

Three major factors are conducive to liquefaction: ground shaking, a shallow water table, and sandy materials. In terms of ground shaking, the selected hazard level of MMI VIII is capable of generating cyclic stresses strong enough to cause liquefaction in the study area. The predominant minimum intensity for coherent slides and lateral spreads and flows is MMI VII. The lowest intensity reported is MMI V (Keefer, 1984). Thus, the study area will experience an MMI of 1 to 2 above the predominant minimum liquefaction threshold. Shallow water tables and sand deposits coincide in river channels, dunes, beach deposits. deltas, silica sand deposits, flood plains, and other topographic lowlands. In these areas the water table is usually less than two meters deep and rarely exceeds five meters.

Areas susceptible to liquefaction are mapped according to geomorphic setting, landforms, types and age of geologic deposits,and water table depth These factors are used to estimate areas of high, moderate, and low susceptibility. In large scale mapping, more refined methods based on boring logs and standard penetration tests (techniques developed by Seed and Idriss, 1971, and Seed, 1979) may be used to determine liquefaction potential. Included in areas of moderate to high susceptibility are Holocene beach deposits composed of sand consisting of grains of quartz, volcanic rock and shells. Thickness ranges from one to five meters. A second area is found in the Carolina quadrangle where fine to medium sands are present on beaches, coastal dunes, and abandoned beach ridges. It is usually not thicker than ten meters, and the water table is less than two meters. Areas of high susceptibility include the very fine and loose sands of Cangrejos Arriba with a thickness ranging from one to four meters and a high ground water table. Within these zones the ground failure potential is high in areas lacking lateral confinement, differentially loaded, loose sand deposits, or gentle slopes. Areas of low to moderate susceptibility include the older deposits of Holocene-Pleistocene age composed of almost pure silica sands derived from ferruginous sand by leaching. Loose sands are present on the surface. The degree of compaction increases irregularly with depth. Kaye (1958) noted the following features: 1) Great uniformity of sorting of the sand material 2) Lack of carbonate cementing material 3) High dry strength, imparted by clay, that acts as a binder 4) Erratic variation in the density of the sand with depth. Zones of low susceptibility are older Pleistocene silica sand deposits in the Bayamón quadrangle. They are one to four meters thick, and the water tables are generally deeper than in younger deposits. The liquefaction potential is not exclusive of beach and silica sand deposits,but a very high potential is locally present in river channels, deltas, uncompacted fills, and lagoonal and flood plain deposits less than 500 years old. Due to map scale limitations these areas are not mapped independently. Swamp and lagoonal deposits (hydraquents) are extensive in the study area and were mapped separately as zones with high liquefaction potential. Recent flood plain deposits are vulnerable where the alluvium is composed of cohesionless materials such as silt, silty sand, or fine grained sand. Most of the alluvium in the study area is composed of clay, sandy clay, and sand. Liquefaction induced flow failures and lateral spreading toward river channels are likely to occur where saturated sand lenses are present. Lateral spreading of flood plain deposits toward river channels destroyed more than 200 bridges during the 1964 Alaska earthquake. They are particularly destructive to pipelines and water mains, a factor which impeded the effort to fight the fire that ignited during the San Francisco earthquake (Hays, 1981). During the 1918 earthquake the Aguadilla water supply pipe over Rio Culebrinas was ruptured by compression when the concrete piers supporting the pipe moved more than 2 meters towards each other across the stream (Reid and Taber, 1918).

Liquefaction damage assesment requires the mapping of potentially susceptible sedimentary materials (table 2), the estimation of the percent area affected by liquefaciton, and the estimation of the damage ratio. Liquefaction mapping criteria have been presented above. The estimation of the percent area affected by liquefaction is done by adapting the procedures proposed by Rice (1983) based on the topographic and geologic conditions, soil profile characteristics, level of earthquake shaking, and liquefaction potential assesment using Seed's (1969) criterium. The resercher's subjective judgement is critical in the evaluation, specially when detailed data is not available.

The percentage of area affected by liquefaction and the corresponding damage ratio for a magnitude 6 earthquake is shown in figure 18. The selected earthquake hazard level (MMI VIII) approximately corresponds to a peak ground acceleration of .2g. and an earthquake Richter Magnitude 6 (fig 19). Figure 16 gives the probability of liquefaction for areas where the Standard Penetration Test blow counts are uniformly distributed between 10 and 20 blows. The percent area affected by liquefaction is 17 percent and the damage ratio is .35 according to fig. 18. Because portions of the areas mapped under moderate to high potential have higher blow counts (for example, indurated sand and beach rock) the percent area affected by liquefaction is overestimated. A conservative estimate of the percent area affected by liquefaction based on this researcher's judgement assigns 10 percent to areas of moderate to high susceptibility, and 2 percent to areas mapped under low susceptibility. These estimates can be improved by examining specific site profile characteristics and Standard Penetration Test results throughout potentially liquefiable deposits.

TABLE 2

Estimated Susceptibility of Sedimentary deposits to Liquefaction During Strong Seismic Shaking

From Youd and Perkins 1978

Type of Deposit (1)	General Distribution of Cohesionless Sediments in Deposits (2)	Likelihood That Cohesionless Sediments, When Saturated, Would Be Susceptible to Liquefaction (by Age of Deposit)			
		<500 yr (3)	Holocene (4)	Pleistocene (5)	Pre-Pleistocene (6)
(a) Continental Deposits					
River channel	Locally variable	Very high	High	Low	Very low
Flood plain	Locally variable	High	Moderate	Low	Very low
Alluvial fan and plain	Widespread	Moderate	Low	Low	Very low
Marine terraces and plains	Widespread	-	Low	Very low	Very low
Delta and fan-delta	Widespread	High	Moderate	Low	Very low
Lacustrine and playa	Variable	High	Moderate	Low	Very low
Colluvium	Variable	High	Moderate	Low	Very low
Talus	Widespread	Low	Low	Very low	Very low
Dunes	Widespread	High	Moderate	Low	Very low
Loess	Variable	High	High	High	Unknown
Glacial till	Variable	Low	Low	Very low	Very low
Tuff	Rare	Low	Low	Very low	Very low

(continued)

Type of Deposit (1)	General Distribution of Cohesionless Sediments in Deposits (2)	Likelihood That Cohesionless Sediments, When Saturated, Would Be Susceptible to Liquefaction (by Age of Deposit)			
		<500 yr (3)	Holocene (4)	Pleistocene (5)	Pre-Pleistocene (6)
(a) Continental Deposits (cont'd)					
Tephra	Widespread	High	High	?	?
Residual soils	Rare	Low	Low	Very low	Very low
Sebka	Locally variable	High	Moderate	Low	Very low
(b) Coastal Zone					
Delta	Widespread	Very high	High	Low	Very low
Esturine	Locally variable	High	Moderate	Low	Very low
Beach					
• High wave energy	Widespread	Moderate	Low	Very low	Very low
• Low wave energy	Widespread	High	Moderate	Low	Very low
Lagoonal	Locally variable	High	Moderate	Low	Very low
Fore shore	Locally variable	High	Moderate	Low	Very low
(c) Artificial					
Uncompacted fill	Variable	Very high	-	-	-
Compacted fill	Variable	Low	-	-	-

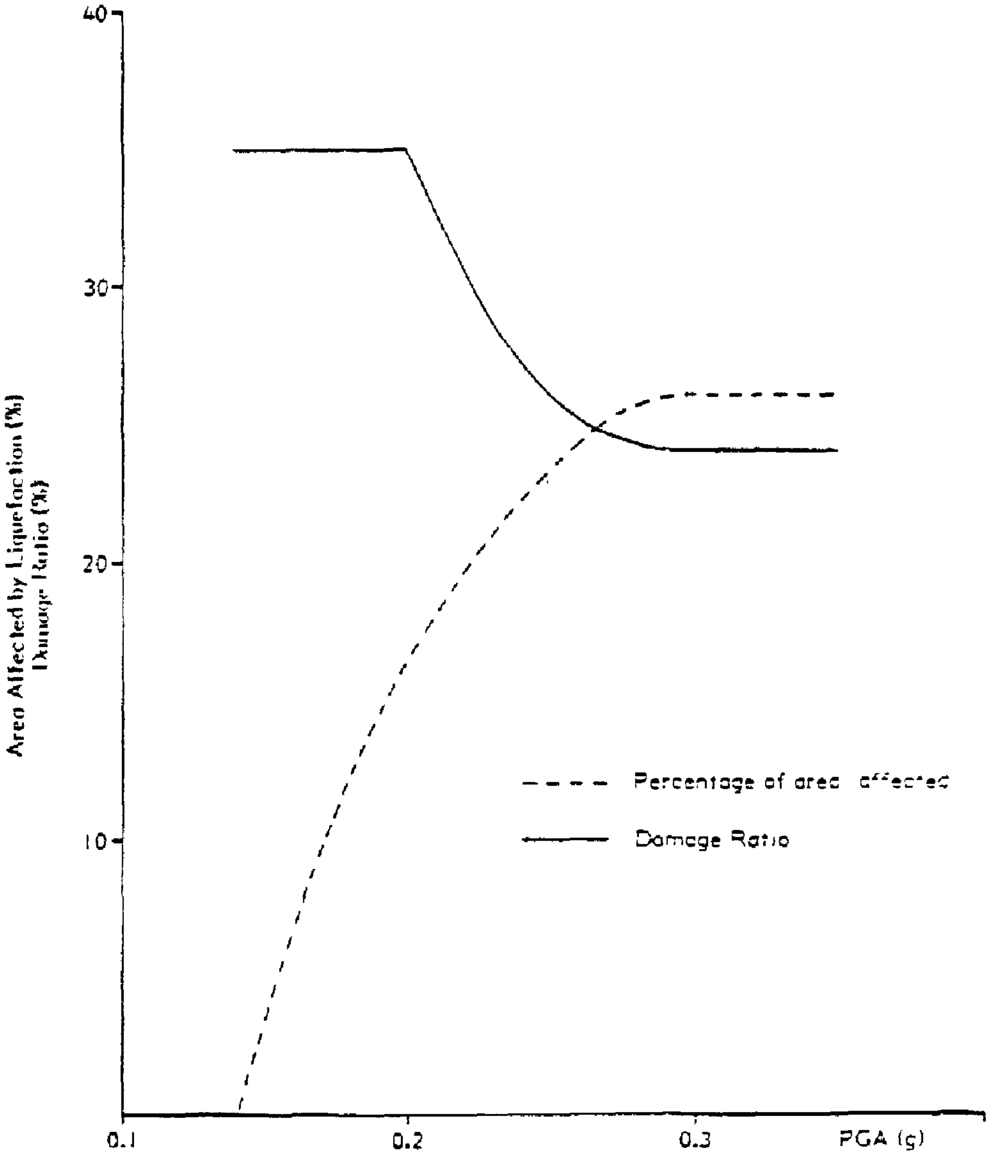
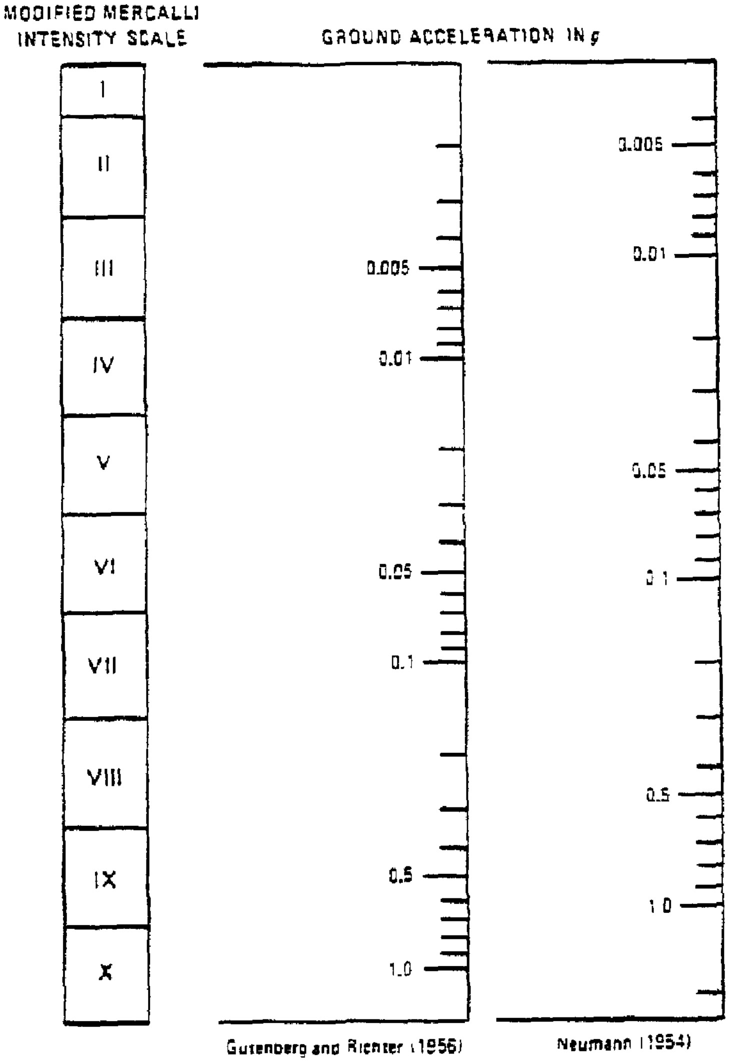

LIQUEFACTION POTENTIAL
PERCENTAGE OF AREA AFFECTED
FOR A MAGNITUDE 6 EARTHQUAKE

Fig. 18



Intensity and Acceleration Relations Proposed by Neumann, and Gutenberg and Richter

Fig. 19 From Hays 1980

Landslides

The term landslide, as used in this report, refers to all types of slope movements including falls, flows, slides, and topples.

Two main features that control earthquake induced landslides are slope inclination and the types and characteristics of the geologic materials beneath the slope. Ground motion can trigger landslides when slopes are subjected to repeated loadings consisting of irregular pulses that weaken and eventually loosen rock and soil materials forcing them down the slope. Keefer (1984) studied the relationship between earthquake magnitude and areas affected by landslides, and the epicentral distance and Modified Mercalli Intensity at which different landslides occur. Areas affected by landslides show a strong correlation with magnitude. Generally, landslides are caused by events greater than M. 4.0. The selected hazard level can trigger landslides over an area up to 100,000 km^2. This is extensive enough to cover the whole island of Puerto Rico, assuming the epicenter of the selected hazard level is along the southern wall of the Puerto Rico Trench. In addition, the epicentral distance from the study area is closer than the minimum distance of 200 kilometers required to experience all types of ground failure. At a given epicentral distance, different areas experience different intensities. The selected hazard level will produce an MM intensity of VIII to IX (deep alluvium), a value up to 2 intensities above the predominant minimum seismic shaking intensities required to trigger disrupted slides and falls (MMI VI) and coherent slides, lateral spreads, and flows (MMI VII). Thus, ground motion in San Juan, given the areal, epicentral, and intensity characteristics of the selected hazard level, is strong enough to cause landslides, especially in steep slope areas and near weak geologic materials. The mapping of areas susceptible to landsliding takes into consideration slope inclination as a primary factor affecting slope stability. In general, steep slope areas are chief sites of instability mainly through their control of the downslope component of the weight of slope material. However, the degree of stability depends considerably on the geologic material underlying the slope. Granular non-organic soils with little cohesion and low frictional strength are the most susceptible to failure. In addition, highly fractured or jointed rock, or rock which displays any other type of discontinuity, especially if planes are open, is susceptible to failure (Rice, 1983). Degree of susceptibility to landslides is mapped as high, moderate to high and low.

Zones of high susceptibility in the study area include those areas where geologic formations are characterized by a high landslide incidence due to steep slopes in vulnerable material, and the presence of a weak geologic stata below more resistant ones. Consequently, the Cibao - Aguada and San Sebastian limestone formations, and the Mucarabones sand are areas of high susceptibility. The first two formations show a high incidence of landslides extending along a considerable portion of their outcrop from Aguadilla to the southwestern portion of the San Juan metropotilitan area. The geologic contact along steep scarpments where the Aguada formation rests on clay and sandy clay of the the Cibao formation is potentially unstable. In similar humid, tropical, geomorphic environments earthquakes have triggered rotational slumps involving failure of incompetent, plastic strata beneath limestone (Simonett, 1967). Large landslides occur where the thick clayey beds of the San Sebastian formation beneath the Lares limestone are exposed along a scarpment that extends from Corozal to the west coast (Monroe, 1964). Although the Lares limestone is not present in the study area due to its eastern grading into the Mucarabones sand, steep portions of the clayey and pebbly San Sebastian and the Mucarabones sand are mapped as highly susceptible area.

Areas mapped as moderate to high susceptibility are located mainly at the southern portion of the San Juan metropolitan area where the interior mountainous uplands begin. Slope inclinations range from 12 to 32 degrees but do not show any significant incidence of landsliding except along steep-sided excavations, such as roadcuts (Molinelli, 1983). Soils are mostly Inceptisols, characterized by shallow depth (40 cm.) over slightly weathered bedrock, and Ultisols, moderately deep to deep soils (1.5 m. deep) (Soil Survey, San Juan). When dry, the high clay content of these residual soils imparts a high cohesive stability to the slopes, greatly reducing their vulnerability to the probable earthquake . On the other hand, protracted periods of rain can saturate the soils, increasing the pore water pressure, reducing the shear strength, and increasing the shear stress with the weight of the water. Under these conditions, the probable earthquake can trigger a large amount of debris, earth flow, and slides. In humid, tropical, geomorphic environments similar to those mapped as moderate susceptibility, the percentage area that has failed during an earthquake of similar magnitude as the probable earthquake ranges from 25 to 40 percent (Simonett, 1967; Pain, 1972).

Areas mapped as low susceptibility include nearly flat slope zones (less than 10 degrees inclination) and very stable rock outcrops. Included in this mapping unit are the low relief portions of the San Sebastian formation and Rio Piedras siltstone, the Guaynabo formation, the Guaracanal Andesite, and the Frailes formation. Most of these areas are presently urbanized, a process that has further leveled the topography. There is little likelihood of significant downslope movement, except along excavations. The rock outcrops included within this unit are the Aymamón and Aguada limestone formations and eolianites. In spite of steep slopes, limestones, along with other formations of Terciary age, are considered the most stable rock in Puerto Rico. (Monroe, 1979). Case hardening by solution and immediate redeposition in situ stabilize the slope (Monroe, 1976). Eolianites are very stable except where undermining has taken place due to mechanical and chemical weathering associated with wave action.

Not all slopes with landslide potential will actually fail at the selected hazard level. To estimate the expected percentage area of slope failure, criteria that reflect engineering judgement based on geological data and past earthquake experience (Rice, 1983) are incorporated. A conservative estimate of percentage area of failure assigns a value of 2 to 15 percent to areas of low, moderate, and high susceptibility (Fig.20) These values can more than double if the earthquake occurs after a protacted period of rain when the shear strength of the soil is lower. Landslide damage assessment assumes that for a given landslide potential, the percentage of area affected is the same as the percentage of buildings that suffer landslide induced damage. In addition, damage ratios (percent loss) are shifted arbitrarily by .5 intensity (Rice 1983).

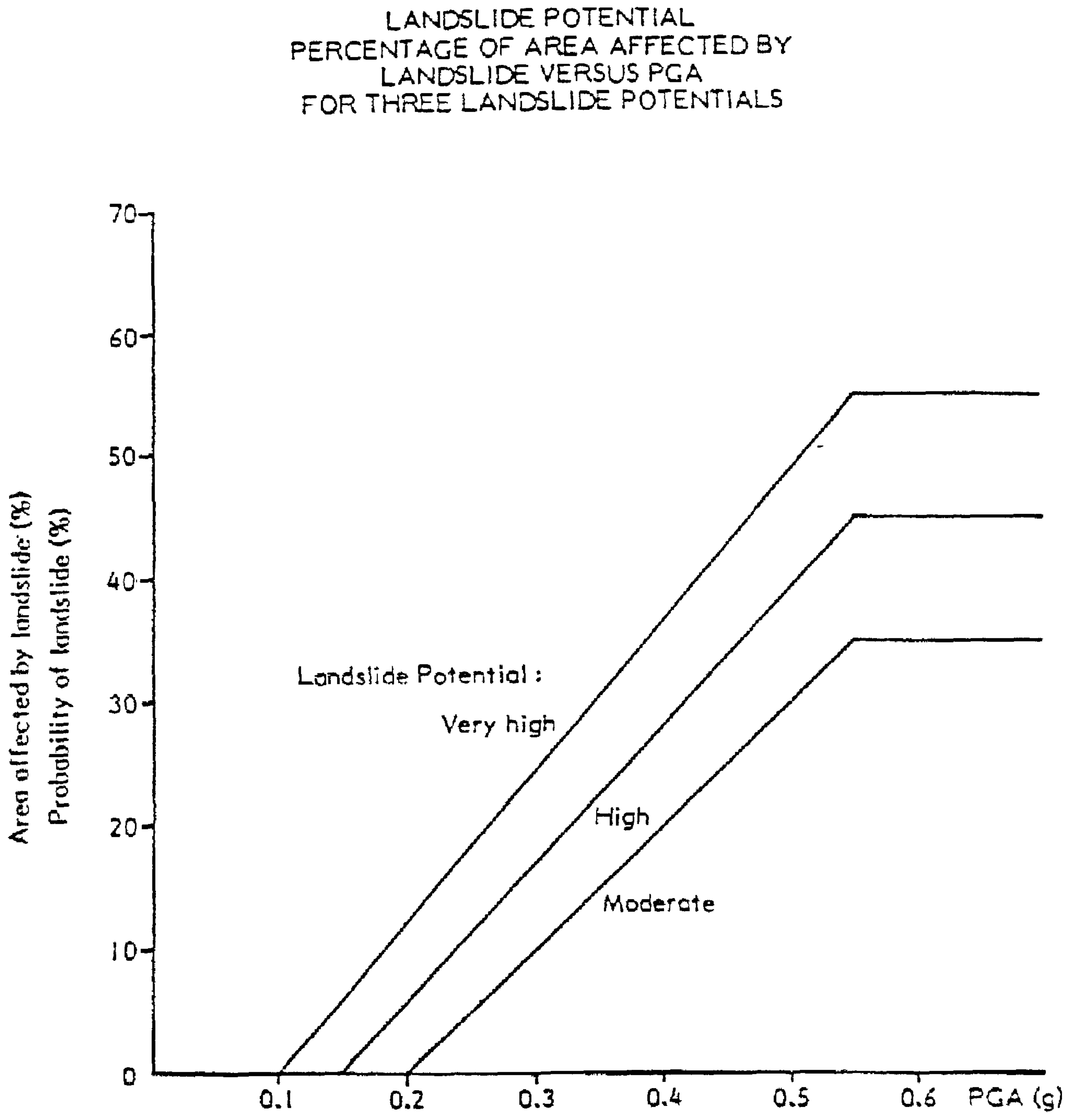

LANDSLIDE POTENTIAL
PERCENTAGE OF AREA AFFECTED BY
LANDSLIDE VERSUS PGA
FOR THREE LANDSLIDE POTENTIALS
Area affected by landslide (%)
Probability of landslide (%)
70
60
50
40
30
20
10
0
0.1
0.2
0.3
0.4
0.5
0.6
PGA (g)
Landslide Potential :
Very high
High
Moderate

Fig. 20