PLANNING AND MANAGEMENT OF REGIONAL DEVELOPMENT FOR EARTHQUAKE DISASTER MITIGATION

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S Y N O P S I S

This paper deals with the Peruvian experience on physical planning to mitigate the effects of natural disasters which have been made at local but not at regional level. Thanks to the invitation to participate in the International Seminar on Regional Development Planning for Disaster Prevention, the author has the opportunity to ponder the problem at regional level and to prepare a plan to operate, almost inmediately, at that level using the experiences and tools already developed.

Microzonation studies consisting in multidisciplinary investigation of the area of interest which typically cover some few square kilometers, take into consideration all possible natural disasters menacing the area: earthquakes, floods, avalanches, landslides, mud and debris flows, etc. Then the area is divided into sectors of different hazards.

When the results of microzonation studies are applied in urban planning, the least hazardous sectors are destined to the most important urban components as high density residential areas and the sectors where economic activities on which the community depends are performed; and the most hazardous ones, to open recreational activities such as parks, soccer fields etc.

Microzonation is also used to select the best location for important public works such as dams, hydroelectric plants, etc., trunk lines of lifeline networks such as water supply mains; as well as the location of critical facilities such as nuclear reactors, big furnaces, gas tanks, etc.

Since it is not possible to study the whole planning region as prescribed in the microzonation method, although necessary for engineering design, the strategy proposed to attain the objectives, is to give priority to the fastest growing urban areas within the boundaries of the region. Also, the method is recommended to investigate the locations of important constructions in the region.

At this stage, when many political decision makers and even some planners need to be convinced that physical planning based on good information of the site natural conditions is the best way to avoid losses it is impractical to try do define an ideal planning region rather than using existing organizations. The political and administrative division of Peru considers 24 departments and a constitutional province. Each one has its own development corporation. Japan-Peru Earthquake and Disasters Mitigation Research Center (CISMID) was created in Lima, Peru, in June 1986, with the technical and economical assistance of the Government of Japan. In November 1987, a one-month seminar on physical planning for disaster mitigation will be organized by CISMID. The chiefs of the planning sections of the departmental corporations and professors on urban and regional planning of the universities of the countrys interior will be invited to participate in the seminar with - first priority.

1. INTRODUCTION

The Republic of Peru is located in the central western part of South America bordering the Pacific Ocean, covering an area of 1,285, 216 km2. Its population is approximately 19,000,000.

Its most important geographical feature is the Andes range which crosses its territory SE to NW practically parallel to the coast covering nearly 40% of its area, leaving a narrow belt of arid desert in the west and a vast wet densely forested jungle on the lower eastern slopes of the Andes. This geographical accident divides the country into 3 natural regions: coast, sierra or highland, and jungle.

1.1 Most frequent natural disasters in Peru

The Andes range is a consequence of the interaction between the Nazca and South America plates, so destructive earthquakes of magnitude 8 are not infrequent, and cause numerous victims and heavy material losses. An example is the 1970 earthquake with a death toll of 67,000 and more than 500 million US dollars in material losses. Secondary effects of earthquakes are tsunamis and avalanches. In 1746 the nearby Callao seaport was destroyed by tsunami waves killing 97% of its 5,000 inhabitants. In 1970 an avalanche triggered by an earthquake from the Huascaran Mountain (altitude 6768 mts.) buried the town of Yungay and 13,000 of its inhabitants.

The delicate oceanic and atmospheric balance, which restricts the Peruvian coastal strip to less rainfall than the Sahara desert and creates a vast ocean wealth in fish and other marine products every few decades, is broken by the so-called "El Niño Phenomemon". The plankton-rich cold ocean wa ter coming from the Antarctic is substituted along the Peruvian coast by the warm, nutrientfree water coming from the mid-Pacific, causing downpour precipitation, heavy damages to the urban facilities and infrastructure not designed for that infrequent phenomenon and the collapse of the fishing industry as occurred in 1983, when the direct losses amounted to (approximately) one billion US dollars. At that time severe drought affected the Peru S-E region, where the Titicaca lake is located. In 1986 there has been severe drought in the northern coast and extensive areas have been flooded around the Titicaca lake.

Landslides, debris and mud flows originated in the steep slopes of the Andes are frequent. Tributaries of the Amazon river which drain large and very rainy basins may raise their level by 10 to 12 meters in a few hours in the high jungle region, and inundate wide areas for weeks or months in the low jungle.

1.2 Economic and social impact caused by disasters

Natural disasters cause a severe impact on the country's normal economic and social development. For example, after the 1970 earthquake and the 1983 floods, special organizations were set up to rehabilitate the affected areas. Thus hundreds of millions of US dollars needed for the country's development were spent to reconstruct those areas.

Such type of extended disasters disrupt the production facilities, increase the impoverishment of the population and accelerate the migratory current to Lima and other important cities on the coast.

For example, the Lima population was half a million in 1940 and it is 5 million at present. In 1983, due to the intense and long-lasting floods on the northern coast and grave drought in the SE region, the gross national product decreased by 7%. It was one of the most important factors, together with the low prices of the export row materials, that severely affected the weak Peruvian economy, making it practically impossible to honor the external debt as programmed with the International Monetary Fund.

1.3 Legislative framework

In Peru the legislation to protect people and properties from natural disasters is very poor. There is no special legislation to take preventive measures in an organized way against destructive effects of natural disasters.

However there is a seismic code approved by the Ministry of Housing and Construction in 1977 (1)* in which the minimun

(*) Reference

requirements for building seismic design are given. In the macro scale the country is divided in 3 seismic zones with - coefficients 1 and 0.7 for the two most active zones and 0.3 for the zone of very low seismicity in the east of the country, near the border with Brazil.

The seismic code also specify that seismic microzonation investigations are necessary for new areas to be occupied for urban expansion, for industrial complexes and similar, and for buildings which house critical facilities such as nuclear - reactors, furnaces, inflammable deposits etc. However, this point is rarely applied, because few politicians, urban planners and engineers understand the techniques and don't know of the possibility to drastically reduce earthquake losses by proper physical planning.

1.4 Disaster relief and natural events investigations

Disaster relief actions are under the responsibility of Peru's Civil Defense System. Its most important body is the National Committee of Civil Defense, whose president is the Minister of the Interior and its members are the Ministers of Health, Agriculture, Energy and Mines, Transportion and Communications, Minister of the Presidency, and the President of the Joint Command of the Peruvian Armed Forces.

The Executive Secretary of that body, with the rank of a vice-minister, actually manages the National Committe. It has several committees, such as the multisectorial, scientific, cooperation, security, etc.

The country is divided politically and administratively into 24 departments and a constitutional province, 149 provinces and 1672 districts.

For the organization of Peru is Civil Defense its territory is divided into 5 regions, each one comprising various departments. Each region has a president and an executive secretary and its own organization. According to the Civil Defense Law there are also departmental, provincial and district committees of civil defense.

There are several institutions regularly investigating natural events some of wich are destructive I.G.P., the Geophysical Institute of Peru, records, studies, processes, and catalogues earthquakes, INGEMMET. The Geological, Mining and Metallurgical Institute, studies external geodynamical phenomena such as: floods, landslides, avalanches, mud and debris flows, etc. SENAMHI, the National Service of Metereology and Hydrology is in charge of the atmospheric phenomena. "Instituto del Mar". Sea's Institute works on oceanographical events. DHINA. The Navy's Bureau of Hydrology and Navigation is in charge of oceanographical phenomena and of the tidal gave stations.

Academic Institutions such as the Catholic University - (PUC), and the National University of Engineering (UNI) investigate earthquake effects and are developing earthquake-resistant constructions. UNI developed a microzonation study method and they are trying to apply it in urban planning and in the selection of the best locations of civil works.

2. BACKGROUND

Existing tools and experiences for disaster mitigation - regional physical planning in Peru.

2.1 Earthquake Damages

To implement a planning and management program to mitigate the effects of any natural disaster at a national, regional or local level, it is very important to have a clear understanding of why and how the damages are produced. In this report, following the advice of the Seminar's organizer, emphasis is being given to the earthquake aspect.

Detailed and systematic field investigations were made by the author and his students of the Peru earthquakes of 1970 1974, and 1979, incurring three, two and one year respectively, when about 30 Civil Engineering thesis were written. Also the restoration projects for close to 3000 brick bearing (BBW) dwellings were prepared and given free to the affected families as a social service. Up to date, the author has participated professionally in the strengthening projects of more than 150 reinforced concrete buildings. From that experience some conclusions may be drawn:

- More than 80% of the damages to engineered reinforced concrete buildings were caused by their inadequate shape and wrong arrangement of their structural elements to withstand horizontal seismic forces, such as short columns, excentricity, weakness in one direction, lack of enough separation between buildings, etc. This caused stress concentration and cracks in the buildings lower levels or damage by impact.

- It was found that a good correlation existed between damages sustained by BBW constructions with rigid roofs and wall density ratio (WDR) and that the R.C. columns and tied beams substantially increase their strength to resist seismic forces.

- Non-engineered construction with a light roof fails in the corner upper part under the action of horizontal bending moment and shear, due to the inability of the light roof to fix the wall upper border. So a tied beam at hte lintel level is very effective.

- The damage survey on weak non-engineered construction such as adobe, whose deterioration to seismic action is very sensitive to changes of earthquake instensity in the intermediate level of VI, VII and VIII degrees of the Mercalli modified scale, that even in the relatively frequent 7-7.5 magnitude range earthquakes cover an important macroseismic area, led to the understanding of their mechanism of failure and to how the local conditions influence the severity and extent of damages. Reinforced concrete buildings with structural defects, and brick bearing wall constructions with low wall density and no reinforcement, suffer important damages at intermediate seismic intensities and helped to develop the seismic microzonation method.

- The local soil characteristics, the geology of the area and the topography have a clear and strong influence on the severity and the extent of the damages. The same conclusions may be drawn from the field investigation made by the author of the 1985 Chile and Mexico earthquakes, and the Armero (Colombia) volcano disasters.

These conclusions, foreseen during the first damage survey made soon after the May 31, 1970 earthquake, and the clear microzonation effects in the Lima area caused by the 1940 (2) and 1966 (3) and previous earthquakes, have guided the author's activities during the last 16 years. In June 1970, he advised the Peruvian Government to request technical assistance from Japan to perform the microzonation studies of the Chimbote area, severely damaged by that earthquake. The idea was that the reconstruction of Chimbote be made with good knowledge of the site's natural conditions. The Japanese Mission, headed by Professor Ryohei Morimoto (then Director of the Earthquake Research Institute of the University of Tokyo) made the studies (4) with the assistance of former Peruvian participants of the International Institute of Seismology and Earthquake Engineering of the Building Research Institute, Ministry of Construction, Japan (5). This is the starting point of the development of the microzonation method and its application to physical planning trying to mitigate the effects of natural disaster which kept the group busy up to the present.

2.2 Repairing and strengthening of buildings damaged by earthquakes.

The main objective of a strengthening and repairing project is to eliminate the causes of the building failure. By comparing the computer results of the structural analysis of engineered buildings under horizontal seismic forces in the pre-earthquake stage with the investigation of the damages sustained by the building by careful field inspection, it is possible to arrive at a sure diagnosis of the cause of the failure. This is also very important to learn how to design new earthaquake resistant buildings.

Reinforced concrete buildings

Most of the damaged reinforced concrete buildings were partially filled with brick walls. When the brick walls do not reach the bottom of the beams, the portion of the columns between the wall upper edge and the beam lower face become very rigid in comparison with full free high columns, attracting much more shear forces than they are able to bear, and thus the portion fails. This is called "short columns".

In other cases, one side of the building is much more rigid than the other so earthquakes excite it in the torsional vibration mode, with larger amplitudes in the flexible side damaging this section.

Many of the damaged buildings were strong enough to take horizontal seismic forces in one direction, but were weak in the other. The few rigid elements in the latter direction were damaged.

The primary cause of failure of 144 buildings, whose strengthening projects were prepared during the 1970s are included in table 1.

The tendency of the buildings damaged and repaired remained the same during the 1980s. In table 1, it is noted that 69% of the failures were caused by short columns and other structural defects, and 12.5% by shear cracks in walls in the weak direction of the buildings. These two exceed 80% of all causes and could be easily eliminated with good design projects.

Undamaged buildings were also studied. It was note that those with concrete shear walls of appropriate size, adequately distributed inside the buildings, did not suffer damages. These results agree with the excellent lectures given by well known professors: Dr. Tachu Naito, Dr. Kiyoshi Muto, and Dr. Hajime Umemura at the International Institute of Seismology and Earthquake Engineering, Building Research Institute, Ministry of Construction, Japan, in the early 1960s, who said that according to the Japanese experience R.C. shear wall is the most effective element to take horizontal seismic forces in low and medium high buildings.

The 3 most common types of structural defects listed above may be eliminated by adding shear walls to the buildings. The rigidity of those elements is so great that it is able to withstand most of the horizontal seismic forces, substantially reducing the shear taken by short columns. When it was possible, the short columns were separated about one inch from the walls in order to improve the seismic resistance of the spatial frame system used as a second line of defense.

By adding shear walls in the weakest direction of the buildings, it is possible to attain good balance in both directions. If shear walls of adequate size are added to the flexible side of the building, static excentricity may be eliminated, reducing significantly the torsional vibration. Also lateral deflexion is better controlled reducing the possibility of being damaged by pounding against adjacent buildings. The final sizes of the shear wall are defined by trial and error computer analysis.

Upgrading each column and beam to meet the seismic code requirement is both costly and time consuming. By adding shear walls the solution is concentrated in few locations and the cost would range from 10 to 25% of the building cost, depending mainly on the extent of the damages and the soil characteristics underneath the building.

Brick constructions

Fig. 1 shows the results of damage survey of hundreds of damaged and undamaged brick bearing wall (BBW) constructions with rigid roof. Good correlation was found between the wall density ratio (WDR) and the damages sustained by those types of construction. The WDR is defined as the total length of wall in the direction being considered, in centimeters, and the construction area in square meters. The wall standard thickness is 25 cm. including 1.5 cm. of cement mortar plaster in each wall face. For thinner walls, for example 15 cm. the WDR is reduced by the factor 15/25 = 0.6.

Fig. 1 also shows how effective RC[1] columns and tie beams are to reduce seismic damages; however, when the WDR is very low, less than 5 cm/m2, doors and windows were damaged.

Adding R.C. shear walls to constructions with rigid brick walls is not as effective as adding those elements to R.C. flexible buildings and may result too costly for relatively small buildings as are usually the BBW constructions. So, to strengthen BBW constructions the method was as follows: walls were cut from the upper border up to the foundation at the corner or about every 5 meters of wall to house R.C. columns. Low size steel bars were added (# 3 or 4). Fresh concrete was then poured, and inverted tie beams were built on top of the roof, resulting in a monolithic unit. The longer dimension of the column cross section was oriented in the buildings weakest direction. Sometimes, for tunnel type buildings, small R.C. shear walls were added in the perpendicular direction of the "tunnel" axis.

Adobe constructions

Methods for repairing and strenghtening non-engineered adobe constructions have been developed, but the number of applications has been minimal; in part because the feasibility study made after the 1970 Peru earthquake indicated that it was not worthwhile to repair adobe constructions, but specially because of the existing very poor diffusion system.

A method to stregthen adobe constructions may be as follows suspend the roof with wooden beams and posts, unfasten the wall upper 4 or 5 adobe rows up to the lintel level. Place there a tie beam of soil-cement with wood reinforcement and replace the adobe rows and roof. Special care should be taken with the reinforcement at the corner.

This method is not difficult to perform because the mud mortar is easy to remove the roof is light, the cost to implement is very low and the method is effective.

2.3 Seismic microzonation

a. Microzonation method

Inhabitants of Metropolitan Lima are well aware of the seismic microzonation effects. Earthquakes that have affected the area since the beginning of this century have shown important differences in the extent and severity of the damages in locations close to each other, depending on the local soil, geology, and topography characteristics. In La Molina, Callao and Chorrillos, all of them located at the edge of the Rimac valley where Lima is located, the seismic intensity has been 2 to 3 degrees higher in the MM scale than in the central part of the valley. At those locations R.C. buildings have been severely and repeatedly damaged, whereas old adobe constructions have suffered only minor damages in the central part of the valley in 1904, 1932, 1940, 1966 and 1974. Also the 1970 earthquake with its epicenter 400 km away, caused important damages in La Molina, but in no other locations in Lima.

The soil of the central part of the Rimac valley consists of dense, compact and dry conglomerate with a bearing capacity of over 5 kg/cm2. The water table is several tens of meters below the ground surface. La Molina is a bowl-shaped valley 2-3 km wide, with fine grain soil and the water table depressed to more than 10 m due to its exploitation. The areas which are affected in Chorrillos and Callao consist of silty and organic soils with the water table close to the surface.

In Peru, microzonation effects have also been well documented in Chimbote and Huaraz (1970), Arequipa, Aplao, Huancarqui, Corire, and Chuquibamba (1979).

Starting in 1970, when microzonation investigation was made for Chimbote city by the Morimoto Mission, the local group set up to assist that mission has continued working up to the present time with minor variations in its members.

Thus a microzonation method was developed during the 1970s (7) when a multidisciplinary group started investigating - all possible natural disasters menacing the areas of interest that typically cover few square kilometers. It is divided into sectors of different hazard its main application being: urban planning for disaster mitigation, selecting - the best location for important civil works and critical facilities and selecting the axis of trunk lines of lifeline networks.
The disciplines included in the method are:

Seismology

Using data of past earthquakes and tectonic setting of the area, future seismic activities of the region is estimated.

Geology

This is one of the basic disciplines in the microzonation studies. Hydrogeology, Geomorphology and Geological Engineering (Known in some countries as Geotechnic) play an important role in the detection and identification of the different natural phenomena which threaten the security of population and civil engineering works, as well as in the decision to select the prevention methods for risk attenuation and/or defense works construction.
In Peru, the geological methodology formerly used in site investigation was the classical one, i.e. survey of the - stratigraphic, tectonic, geohistoric and hydrogeological - features. However, the morphology of the Peruvian territory with strong topographic contrasts which delimit different physiographic units with different lithological, structural, and climatic characteristics, made it necessary to introduce to the classical methodology, the study of the - external geodynamic phenomena applying very particular rules and sequence for the investigation of populated centers and civil works locations.
The external geodynamics studies which include: floods - landslides, alluvions, avalanches, soil slithering and soil fluxion mud and debris flows, etc., are oriented toward the location of the phenomena, the risk determination and the establishment of prevention measures, and/or defense construction methods, zoning the different sectors of the site being investigated and establishing their safety limits.
So, according to the above discussion, the following aspects should be considered:

- Analysis of the site morphological aspect.
- Study of the nature of the bedrock and foundation soil.
- Identification of the risky phenomena to people and constructions.
- Study of the phenomena's origin, its evolution, and the factors contributing to its existence.
- Establishment of prevention methods to minimize or avoid the risk.

- Establishment of the safety limits.
- Preparation of the geological microzonation map.

Soil mechanics, detailed static properties of the soil are found as well as the parameters needed for the foundation design. Also some parameters to be used in the soil modeling for soil dynamical analysis are determined. By using the geological microzonation map it is possible to significantly reduce the soil exploration program and its cost. Important parameters for the soil dynamic studies as P & S wave velocities are measured using down hole and up hole method. Prof. E. Shima of the University of Tokyo very kindly advised the author on this matter. Oyo instruments which are easy to operate and maintain are used for geophysical exploration; an expert from Oyo corporation traveled to Peru to teach the measuring techniques in 1977.
One dimensional soil model was used. Software produced at the University of Tokyo and the University of California at Berkeley was adapted to the computer existing in Peru in the 1970s.
Since there were no earthquake records in the investigated remote areas, they were produced by filtering actual records taken in rock, or by artificial earthquakes, throughout the soil model. By processing the records so obtained, seismic spectra for the site were computed.

Other investigations

When it was possible or necessary the following studies were made: post-earthquake damages survey, simultaneous recording of aftershocks on different types of soils, soil failures, soil liquefactions, tsunami inundation delimination etc.

Earthquake Engineering

The coordination of the investigations, which is very important, was made with the participation of all the specialists and were very frequent. The fact that the Earthquake Engineering specialists determine the final coeficient used for the structural analysis and design helped to fix the extent and detail of the investigation in each field, avoiding unnecessary studies or excessive details in some aspects, and the addition of others when needed.
In this part the whole report is summarized and written in such a way that it may be used directly by the structural engineer. It is specially useful in Peru for civil work design, since the Peruvian seismic code is oriented toward the buildings seismic design. (1)

b. Simplified microzonation method for urban planning

The microzonation method as described in 2.3a resulted too costly and too sophisticated for a developing country like Peru for most of the cases. It has been applied to inves-

tigate the site of important constructions, such as the site of a nuclear reactor, the relocation of a mining town, the site of a hospital complex, the location of a new town in the Amazon jungle (the last one founded by HABITAT) and other few cases. So the necessity for the development of a simpler and cheaper method than the former became apparent, avoiding the use of sophisticated hardware and software and enabling making possible its application by newly graduated engineers and architects promoting broader use of the microzonation.
When the Arequipa 1979 earthquake occurred, it was thought that investigating its effects, corelating the extent and severity of the damages with the local condition of soil, geology and topography, with parameters simple to determine, it could be possible to fulfill the objectives stated above (8).
The principles for the simplification and selection of size of the population to be investigated were:

- Most of the possible future earthquake victims live in the important cities old sections and in small-and medium-size countryside human conglomerates where non-engineered adobe constructions predominate. In those towns only few R.C. constructions of up to 4 stories are built and used as city halls, schools, hospitals and few other public and commercial buildings. For these types of engineered constructions a sound design and a static seismic analysis is enought, so it is not necessary to make soil dynamic investigation or site spectra calculation, so this part may be eliminated from the previous method.

- For an efficient use of the existing town services such as markets, schools, churches, recreational facilities, etc. for the new inahabitants to be settled, the land to be incorporated for urban use in the Peruvian countryside, needs to be within walking distance. So the expansion areas to be investigated are drastically reduced to those areas surrounding the town not further than the indicated boundaries.

- Further simplification may be obtained if the possible expansion areas are divided into sectors of similar characteristics, with respect to soil, topography, geology, present land use, feasibility to install water services, accessibility, etc. Then each sector is graded with parameters easy to determine so that even newly graduated civil engineers and architects may be able to apply the method.

Since the problem is to select the best available sectors, it is not necessary, in many cases, to find the absolute value of the parameters but the relative one i.e., it is enough to consider for example, that flat land is better than that with steep slope, dry soil is better than wet one, etc.

The most important factors considered in the simplified method are:

Topography.- For preliminary rating of the sectors, a field inspection may be enough. Only those selected need to be surveyed since that information is necessary for land development, volume of soil to cut and fill, cost estimation etc.

In wet uncompacted steeped soils, not only the seismic intensity is greatly increased, but landslide may occur as well. On rock those phenomena are drastically reduced with respect to other types of soils in Huarmey (1966), Coishco (1970) and Tiabaya (1979), adobe construction built on undulated rocky areas suffered only negligible damages, while in adobe constructions built nearby, on flat soft ground, the damages were severe. Special care should be taken in inundatable low land.

Geology.- The participation of an experienced geologist or the advice of a local geologist is important. Since Geology is one of the basic investigations, not much simplification is recommended with respect to the former method. The study ends up with a geologic microzonation map of the area, in which the hazard boundaries of different disasters are indicated.

Soil mechanics.- By using the geologic microzonation map, the soil exploration program may be drastically reduced. Open pits are preferable since they only require pick and shovel and it is important to specifyd only soil tests that may be performed in local soil labs. Useful informations easy to find are grain size, soil classification, degree of compactation, water content, thickness of the soil layers, depth of the water table, bearing capacity.

Land use.- In the desert Peruvian coast the irrigation cost is high, so for urban use it is preferable to develop uncultivated instead of irrigated land. Archeological areas which are relatively abundant in Peru are strictly forbidden for any use.

Those areas are reserved by the National Institute of Culture. To avoid wasting time it is necessary to investigate the present land use, and the possibility to use it for urban purposes.

Feasibility to install water services and the accesibility to the area should also be considered. The development cost per hectare is important as well as the foundation cost of each dwelling unit.

Some findings of the Arequipa earthquake effects investigation may be illustrative: Aplao and Huancarqui are two towns located on dry compact terraces elevated a few meters over the elongated Majes valley, while Corire is situated in the middle of the valley, surrounded by rice plantations that require plenty of water to grow.

The 3 towns were located at about the same distance from the epicenter. In the first two, the undamaged or slightly damaged adobe constructions were over 70% and in Corire, most of the adobe constructions were severely damaged. In Aplao, the only damaged constructions were those built in the new area being developed, invading cultivated wet land. The studies indicated that Aplao and Huancarqui should expand on the dry terraces, and in Corire quincha constructions should be built instead of adobe constructions.

In Chuquibambas Belem quarter located in a tonguelike area, with about 30% of slope and sand and silt wet soil, the adobe constructions were notoriously more damaged than in other flat areas of the town with the same soil characteristcs.

In Pampacolca, a small shallow river is located in the border of the town. In about two blocks parallel to the river the damages were larger than in the other areas. Since the town is underpopulated, it was recommended to densify the blocks located beyond 2 blocks from that river.

2.4 Peruvian experience on physical planning to mitigate the effects of natural disasters.

The maximum benefit may be obtained from the microzonation studies, if the area to be developed is used without any other restrictions than those dictated by the site natural conditions. In this case, the area of interest is divided in sectors of differing hazards, considering all possible natural calamities that may threaten that area. The safest sectors are then appointed to the most important urban components such as the high density residential areas, and to the activities on which the economy of the community depends, and the most hazardous sectors are appointed for open recreational areas, parks and other adequate uses. Examples of this case are the planning of the town called "Constitucion" founded in the Peruvian Amazon jungle in 1984 (9) of and those along the open spaces of the 100 kms. of the Metropolitan Lima sea shore (10).

It is interesting to note that the conceptual solution for both cases was similar. Floods caused by rise in level of the Palcazú river which drains a large basin of one of the most rainy areas in the Amazon jungle, and floods caused by tsunamis generated offshore in the Pacific Ocean, were of prime concern. Land strips close to water bodies having a high probability of flooding, were designated for recreational purposes and other water related activities. In the next strip, which only floods on extraordinary occasions, the only constructions permitted are those of low cost and those that do not gather large numbers of people. See figures 2 & 3.

However, even though no such an ideal condition prevails, it is still possible to take effective planning measures to mitigate the effects of natural violent events. For example, if a relatively large lot has been designated for an industrial complex, hospital, or an educational complex, etc., investigation of the area may give good information to make the pilot plan of the facilities according to the degree of hazard in the different parts of the lot, and taking in consideration the direction of attack of natural events. Hazards are then drastically reduced.

To illustrate this point, 2 examples in which the author has directly participated are given:

- When the group receiving a lot, in the high Amazon jungle about 250 kms. east of Lima, designated for a hospital project, the area had been flooded by a river. The lot was large enough so the hospital main facilities were moved in the plot plan, withdrawing them from the river, but not much because there was a hill behind, that could generate mud flow. The final location was decided after a local site study was made. See Fig. 4.

- The torrential rainfall originated by the El Niño phenomenon caused around one billion US dollar damages in the desertic northern Peruvian coast. The National Polytechnical School "Alejandro Taboada" located in Talara some 1,000 km. north of Lima was badly damaged in part by the erosion of eolic sand by flooding. Only by exchanging the land use between the workshops which were the affected buildings, and the soccer and basket ball fields, was it possible to avoid abandoning the facilities which were 65% undamaged and therefore substantially increase the campus safety in future similar events. See Fig. 5.

Very valuable lots are located in many cases in hazardous zones such as in downtown Mexico city, the financial district of San Francisco, CA, the low land of Tokyo, Japan, and La Molina and La Punta in Lima, Perú, but their size only covers the building dimensions.

In these cases, there is no possibility of changing the location of the construction within the lot, but to protect them from natural disasters that menace the lot. Consequently, the site natural condition has to be investigated very carefully.

In all the examples given above except the last one, the seismic intensity is increased sharply due to poor condition of the soil as compared with nearby areas with better soil.

The damages survey of past earthquakes and the investigation of the dynamic characteristics of the soil and those of the buildings may give a good hint to obtain the best solutions. For example, in Mexico city, rigid buildings with enought shear wall to take the horizontal seismic load were undamaged during the 1985 earthquake. Besides, tall buildings with their natural period of vibration much longer than 2 seconds as the Latin American tower (44 stories), the Holiday Inn Crowne Plaza Hotel (25 stories) and others, were also undamaged. On the other hand, flexible buildings with a natural period of vibration of near 2 seconds were severely damaged as they were subjected to several (practically) harmonic waves of about 2 seconds. Flexible buildings initially with their natural periods shorter than 2 seconds, were also severely damaged. As they were deteriorating, their period increased, approaching the resonant condition at two seconds.

In La Molina, Lima - Perú, a low density residential area, flexible 2-to 4-story and inverted type buildings have repeatedly been severely damaged in past earthquakes, but 1-to 3-story brick masonry bearing wall constructions, strengthened with reinforced concrete columns and tiebeams, have remained - undamaged during past earthquakes. That is the type of buildings which are being recommended for the area.

La Punta-Callao, a built-up residential & summer resort area, located on a low-laying peninsula, is threatened by tsunami waves. By placing concrete shear wall parallel to the direction of attack of the waves, the area exposed to water presure is drastically reduced, at is also the possibility of being damaged. In addition, foundations need to be protected from scouring.

In a complex topographical bathimetric setting such as La Punta-San Lorenzo island the direction of attack of the tsunami waves is not obvious. Refraction curves drawing, with the scale enlarged in shallow water near the shore, may give a good indication of the direction of attack.

2.5 Efforts to improve the architectural education on seismic design for buildings and physical planning for disaster mitigation.

Before the first participant in the regular course of the International Institute of Seismology and Earthquake Engineering, IISEE, returned from Japan in 1962, earthquake design of buildings was only a small part of the structural engineering course. In 1963, Earthquake Engineering was taught for the first time in Peru at the Faculty of Civil Engineering of the National University of Engineering in Lima. The course - content was strongly influenced by the lectures and class notes of the courses given at the IISEE. For example, the Prof. K. Muto Method for seismic buildings design is widely used -

in the country. At present EE is included in the curricula of all civil engineering departments in Peruvian universities. To this effect the former participants of the IISEE, up to now more than 50, have played an important role.

The Dean of the Faculty of Architecture of UNI was accompanied by the author during the first field inspection of the Peru 1970 earthquake. The group was so impressed by the number of victims and the severity and extent of the damages, that during the trip it was decided that an introductory course on Earthquake Engineering should be taught at the Faculty of Architecture of UNI, giving emphasis to the shape of the buildings and the arrangements of resistance elements such as shear walls and columns, inside the buildings, in consideration of the types of damages observed.

As the microzonation method as well as its application to urban planning was being developed it has been gradually introduced in the course being taught in architecture during the last 15 years. However, this knowledge is only made available to a small fraction of the students that need it.

2.6 Seismic vulnerability of important human conglomerates

Protecting the largest cities from natural calamities is important for the harmonious development of a region.

The experience seismic vulnerability investigations of Lima built up areas may be useful in this aim, which were made mainly from 1973 to 1978 (11) and still continue (12), (13). To estimate the degree of damages on different types of buildings, a table was prepared using the experience obtained investigating the 1970 earthquake damages and the expected seismic intensities in different sectors, using the isoseismal maps of past eartquakes and the soil, topographic and geological information of the area. According to their use the buildings were classified as dwellings, hospitals, schools, industrial facilities and others. The possible damages to lifeline networks were also studied: water and sewage services, transportation, communication and energy supply, as well as the earthquake secondary effects such as fire and tsunami. Each theme was assigned to one student preparing his civil engineering thesis, except for the dwellings. In the latter case the large Lima Metropolitan area was divided into districts for each case study. In total about 20 thesis were prepared in a 5-year period.

It is interesting to note the evolution of the method used. At the beginning of the studies, the method used was: The district to be investigated was divided into sectors of similar characteristics from the viewpoint of site natural conditions, type and age of buildings, etc. Then each sector was investigated statistically taking 10% of the buildings out of 5% of the blocks. Then the possible damages were presented in 5 different colors.

When aerial photos at scale 1/2500, kindly supplied by the Peru Air Force become available, the whole area was surveyed discrimining construction materials used in the buildings, the street width, height of buildings, etc. Adobe construction, the great killer of when earthquakes occur in Peru, was of major concern and was presented in red in the plotted maps.

When the job was finished it was discovered that the hazardous areas were those within the city boundaries of the 1930s. By reviewing the construction method used in the past together with the regulations used, it was found that after the 1940 Lima earthquake (Magnitude 8.2) adobe constructions were forbidden in Lima. At that time the population of Lima was one tenth of the present population of 5 million. Considering that at that time not all constructions were of adobe and that some have been substituted specially in comercial areas where the land cost is high it is possible to estimate that at present, 6 to 7% of the Lima population is endangered by the failure of adobe dwellings.

For a quick vulnerability study of buil-up areas, the latest method used may be useful, i.e., checking the city grouth delimiting the areas occupied every 10 years or so, studying the technology and material used estimating the possible cumulative damages causes by past earthquakes, and finally estimating the possible losses.

2.7 Construction systems for low cost housing

In destructive earthquakes, most of the victims are of the lowest income social stratum, so it is necessary to develop safe construction methods according to their economic possibilities.

Some efforts have been made in Peru in this connection, specially on adobe research. At the Catholic University of Peru (PUC), the group headed by Prof. Julio Vargas has carried out extensive investigation on adobe seismic structural behavior both statically and dynamically. At the National University of Engineering (UNI), the group guided by the late Professor Ricardo Yamashiro and Professor Roberto Morales a pioneered adobe investigations in the country and made a significant contribution on adobe as construction material, using a small amount of asphalt to stabilize the soil against water, as well as on the structural behavior of adobe assemblies.

Notwithstanding that those investigations have increased the seismic resistance of adobe construction in several hundreds percent, a caution is recommended: make compulsory the seismic microzonation studies of the area before massive adobe constructions are made. In La Molina a suburb of Lima and in Andahuasi, 120 kms. north from Lima, adobe construction - built on seismically unfavorable soil has been repeatedly damaged in past earthquake.

The development of a new technology to built a safe, confortable and inexpensive dwellings is very desirable in a developing country. Taking as a base the "Quincha" a traditional Peruvian construction, which has a good temperature and sound isolation characteristic, a new construction system was developed by the author (15) using some innovating ideas as: prefabrication of modular panels, mass production for cost reduction, quality control "in plant", division of the construction process in steps simple to perform, making the system appropriarte self construction and disaster relief programs in developing countries, and using abundant and cheap construction materials.

The basic element of the system is a wool frame panel 1.2 m wide and 2.4 m high, with 2 additional horizontal elements. On top of this frame bambu canes are waved. There are also door and window panels. All these elements including posts, tie beams, and roof beams are prepared in plant. The plant is very simple and only require the equipment needed in a carpentry.

Transported to the construction site, the elements are joined over prepared concrete floors. Then the walls and roof are covered with mud+straw plaster. As finishing, 3-4 mm. cement, sand and gypsum mortar are used. It was discovery by accident that, if the mud plaster is cracked, the finishing penetrates there, obtaining a good bond, acting as a sandwich. In this way the lateral resisting strenght is controlled by the cement mortar. As the system is light, is able to take "C" at UNI laboratory, on a ful scale model as tested so may be built on any type of soil horizontally. A sample house of 37.2 m2 was built at ININVI to solve all the construction details and then to determine its actual cost. The modular prefabricated quincha construction cost 60% less than a brick masonry construction, with similar finishing.

The system is rapidly expanding in Peru and 300 dwelling units were built in Tumbes as a relief program after the torrential rain and subsequent inundation cause by "El Niño" - phenomenon in 1983. The system has also been used in Popayan Colombia, for the homeless, caused by an earthquake which affected that area.