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INTEGRATED CODE FOR MULTIHAZARD MITIGATION

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ABSTRACT

This code seeks to protect people and man-made constructions, especially buildings and lifeline networks, from the most frequent and damaging natural phenomena: earthquake, flooding, soil failure and volcanic activity. Lessons learned from past disasters show that soil, geology and topography strongly influence the degree of damage and its geographic distribution. Mitigation measures put emphasis on considerations of site hazard degree, importance and functions of constructions, and the seismic behavior of the most popular types of buildings. Key components of lifeline systems are recommended to be located outside high hazard zones.
Forces generated by some events such as flash floods and pyroclastic-flows are so strong, that mitigation measures consist simply of avoiding places threatened by those phenomena. Mainly earthquakes and high wind loads are considered, but since regulations on the malter are well established, only general guidelines are included.

This paper was written bearing in mind the most critical problems affecting many developing countries: the occupation of very hazardous sectors for urban uses, inadequate structural setting of engineered buildings to take horizontal seismic forces, and the widespread use of low strength material such as adobe for housing, in most cases with no mitigation measures at all. Some recommendations are given on these topics.

KEYWORDS

Multihazard code, site hazard, earthquake risk, flooding hazard, soil failure, volcano hazard, lifelines protection, adobe housing,masonry construction, R.C.buildings,microzonation, land use planning.

1. OBJECTIVES

The aim of this code is to try to protect people and man-made constructions, mainly buildings and lifeline networks, from the negative effects of all natural phenomena that may threaten them: earthquakes, floodings, soil failures, volcanic activities, etc.

2. STRATEGY

Apply knowledge gained in past natural disasters with respect to the behavior of man-made constructions during such events: forces acting upon them, their effects and the influence of the natural site conditions --soil characteristics, geology and topography-- on the degree of damage and its geographic distribution.

3. SCOPE

This code sets out requirements for general locations of buildings and lifeline network components, depending on the site characteristics and the importance of constructions. It includes only general guidelines of minimum design loadings for dead, live, earthquake and wind forces.

In cases of very strong acting forces such as those generated by debris flows or lateral volcanic blast, the mitigation measure is simply to avoid constructing in such locations. In most of the cases it is unpractical and too expensive to take such forces with designed structural strength.

Where a detailed earthquake and wind design code exists, this document may be used as a complement of such a document to consider the effect of other extreme natural events.

4. LEARNING FROM PAST NATURAL DISASTERS

From damage surveys made after the occurrence of natural disasters, it has been concluded that the natural site conditions: soil characteristics, geology and topography have had a strong influence on the degree of damage and its geographic distribution. By investigating these conditions and applying their results, it is possible to drastically reduce the negative impact of extreme natural events.

4.1 Earthquakes

Earthquake damage surveys have shown that thick, soft, water-saturated soil, reclaimed land, filled soil and similar types of soils, substantially increase the earthquake damage in comparison with compact, dry, competent soil, increasing the damage on buildings and lifeline networks. This phenomenon, called the microzonation effect, has been observed in many earthquakes i.e.; Loma Prieta, 1989, at the Marina District in San Francisco, California; in Mexico during the 1957 and 1985 earthquakes, at downtown Mexico City, at the bed of the old Texcoco Lake; in Chimbote & Huaraz during the 1970 Peru earthquake; and in Lima, Peru, during the 1908, 1932, 1940, 1966 & 1974 earthquakes, to mention a few examples.

From a dozen earthquake damage surveys made in Latin America, most of them in Peru, during the last 3 decades, it may be concluded that:

It is possible to group the most important types of building class and identify the most likely type of damage they may suffer in case of intense earthquakes.

- Earthen: adobe or tapial (large soil blocks compacted in situ inside wooden forms), stone masonry constructions, with light and flexible roofs. As the walls upper border vibrate freely, they fail by flexure, with the main cracks located at the corners, going downward. After the walls are isolated they fail easily, specially their upper part; but sometimes the whole wall colapses.

- Masonry constructions with rigid and heavy roofs. Their lateral strength depends on their shear resistance provided by their wall density and the addition of reinforced concrete columns and tie beams.

- Reinforced concrete buildings: Most of the failures were due to the structural setting being inadequate to take horizontal seismic forces which originates critical points of stress concentration such as short columns.

Other common structural misconception are: Building's strength unbalance in its two main directions. When the weak direction was the same direction as that of the short columns, heavy damage occurred, even at moderate seismic intensity. VII to VIII MM. Unbalance in the building's horizontal rigidity, creating excentricity, torsional vibration and damage on the flexible side. Insufficient separation between adjacent buildings, or part of them separated by construction joints. Damage caused by impact.

4.2 Floodings

Fresh water floods, tsunami floodings and floods generated by high winds are greatly influenced by the morphology of the river bed, the bathymetry of the tsunami wave path, and the bathymetry of the sea bed near the coast, respectively; as well as the topography and geology of the flood zone.

Flash flood type inundation usually occurs in mountainous areas and its severity depends mainly on the volume of water and mobilized materials and their characteristics, the slope and narrowness of the gorge and location and morphology of the deposition area. In most cases, due to the great energy carrying the material, it is unpractical to try to build structures to withstand such great forces.

Riverine type flooding, or overflooding, usually occurs in flat or gently sloping areas. The rise in the river level occurs in hours or days, depending on the size and characteristics of the basin, rain intensity and distribution. Generally the water force is not so great; however, depending on the morphology of the area and the soil characteristics, if the flooding is accompanied by significant erosion, this phenomenon may be very damaging over extensive areas. Earthen constructions and sewage systems may suffer irreparable damage if flooded during a long period of time.

The severity of a tsunami damage depends on the bathymetry of water shallower than 100 to 200 m. If deep water goes right up to the coast, the energy lost by friction on the sea bed is minimum, and if the coast is high i.e. cliff, and a U or V-shape bay is open to the sea, the energy is concentrated on the bay tip, and the tsunami wave may reach over 30 m. above the mean-sea level, as happens in the Sanriku region of northern Honshu, Japan, where both conditions are present. The Hawaiian Islands are one of the most tsunami-prone regions in the world, because they are surrounded by deep ocean water so tsunami research and information centers are located there, as they are most affected by distant tsunamis. However over 90% of the damaging tsunamis are generated nearby, in the subduction zone. So by looking at a world tectonic map, it is possible to locate the places where tsunamis are most likely to occur.

On the other hand, where shallow water penetrates far into the ocean from the shore line, in the case of cyclones the high wind constantly blowing coastward causes the water to pile up, because the sea bottom friction does not permit the water to return back. Successive high waves flood inland sometimes like walls of water, causing severe damage. In the Gulf of Bengala with the mentioned bathimetry characteristic and extensive low land, two storm surges have caused hundreds of thousands of victims in the last few decades.

But a cyclone may also cause severe damage far inland. As it carries a great amount of water vapor, when it hits a cold front or a cold high mountain, quick vapor condensation occurs causing a downpour of rain as happened in the Trifinio Region, (the common boundary of Honduras, Guatemala and El Salvador) on June 7, 1934. Antigua Ocotepeque, located in the deposition area of a river originating in one of the mountains, was erased from the map. The city was relocated a few kilometers away. Unfortunately the original area is now being resettled.

4.3 Soil Failures

Two main types of soil failure are considered: Soil liquefaction and landslides. These phenomena are well known to earthquake engineers, so further comments are not necesary.

Former or present river beds and beaches are prone to soil liquefaction.

In mountainous regions, landslides may be the main cause of damage, as happened during the Guatemala 1976 earthquake. More than a thousand landslides were reported, interrupting roads, damming rivers and burying villages.

During the 1970 Peru earthquake a huge avalanche originating in the north Huascarán peak (6,768 m) was triggered by vibrations. The town of Ranrahirca was buried; and 13,000 people were killed in the city of Yungay. Ranrahirca had been previously hit by an avalanche in 1962. During a visit to the area in May 1995, the 25th anniversary of the 1970 earthquake, no sign was seen that not long ago hundreds of people had their home in Ranrahirca.

Landslides generated by heavy rain occur extensively around the world, even in areas of relatively gentle slopes, depending on the soil characteristics. Floods and landslides are the costliest natural phenomena to the world economy.

In cases of urban expansion or the location of important civil works in arid or semi-arid regions, an eye should be kept on possible soil expansion or collapse. A relatively simple and low-cost geotechnical investigation may provide adequate information for a sound engineering solution.

4.4 Volcano hazard

The most hazardous phenomena during a volcanic explosive eruption is the collapse of vertical columns containing fragmented magma, ash and rocks at high temperatures 700° - 800°C. These materials are ejected at high speed, more than 1,000 Km/H. The height of the column depends on the energy of the explosion, the volume of magma and rock, and the rate at the which eruption column rushes from the vent.

When the eruption column collapses around the vent, and flows of ash and larger fragments spread out from the eruption center as hot avalanches, the so called pyroclastic-flows occur. The heavier materials flow along the bottom of the river valleys, but gases and ashes do not; they expand over hills and other geographic features.

This phenomenon may extend dozens of kilometres around the volcano and is particularly dangerous in small volcanic islands, where populated areas are located near volcanoes. For example, St Pierre, a town located some 6 km from Mt Pelée in the Martinique island, in the Caribbean Sea, was blasted by pyroclastic-flows in May 1902, and its total population of 28,000 inhabitants was killed within seconds. The hot material bursting upon St Pierre at great speed filled every room and cavity as the gases expanded into them.

Mud-flows fed by water from melted glacier ice and snow in the path of hot lava-flows and very fast-moving pyroclastic materials are the other greatest volcano hazard. Mud-flows may reach hundreds of kilometers away from the volcano along a river valley head on the volcano summit. This phenomenon is particularly dangerous in high snow-capped volcanoes due to the great volume of ice and snow accumulated there. For example, the Monte del Ruiz volcano (5,200 m) located in Colombia, erupted in November 1985. The mud-flows generated around the Arena crater flowed through a narrow river valley called Lagunillas and buried the city of Armero, killing 23,000 of its 30,000 inhabitants. Armero was ill-located with respect to Monte del Ruiz, just at the mouth of the river on its deposition area.

Lava-flows are usually a hazard a few kilometers around the volcano, confined to the slopes surrounding it. They threaten properties, but cause few victims.

Ash-fall is the most widely distributed hazard and may affect areas thousands of kilometers from the volcano, depending on the volume of material emitted, the height of the erupted column, and the wind direction and speed.

The most useful information for protecting people and taking disaster mitigation measures is a volcano hazard map. In South America, high volcano hazard maps, look like an octopus with the head at the area around the volcano summit where the pyroclastic-flow and lava-flow are more likely to occur; and the river valleys, where the mud-flows run that may reach hundreds of kilometer away from the volcano, are the tentacles.

5. MULTIHAZARD MITIGATION MEASURES

The main purpose of the disaster mitigation measures recommended here is to provide a contribution to reduce the most critical problems affecting many developing countries, namely:

- Disorganized and explosive population growth of urban conglomerates occupying with increasing frequency marginal, very hazardous sectors; and when vital services are provided, they are also at high risk.

- Many engineered buildings do not have a sound structural setting to take horizontal seismic forces, and

- A large percentage of non engineered buildings are constructed with low strength material such as adobe, and when they are constructed on soft humid soil are subjected to high seismic intensity or submerged under water, the damage is total.

5.1 Site hazard degree considerations

The site hazard degree is classified as high, moderate and low.

- **High:** Very soft water saturated soils, recently filled and reclaimed land located in a high seismicity region, where soil liquefaction and settlement is most likely to occur.

- The bottom of narrow valleys head on mountains from where violent flash floods or lahars (volcanic mud-flows) may be originated, including the valleys deposition zones.

- Areas subjected to riverine type flooding with very strong current and erosion forces.

- The tips of V or U shaped bays located in the vecinity of areas where to occur tsunamigenic earthquakes. are known to occur

- Zones where the probability of occurrence of avalanche or landslides is high.

- Areas surrounding a crater of an active volcano and may be affected by pyroclastic or lava flows.

- **Moderate:** Areas where important to moderate seismic wave amplification are expected, but not soil failures. Zones subjected to moderate riverine type and tsunami floodings. In general, areas where the threats from natural phenomena are moderate.

- **Low:** Compact dry land with good to high soil-bearing capacity. Not threatened by floodings, soil failures or volcanic activities.

5.2 Clasification of construction according to their importance and their functions

According to construction the importance and function of different constructions are classified as: Important, average and low.

Important: Buildings that are indispensable when disaster strikes, such as hospitals, fire and police stations, and places where great number of people are gathered such as stadiums, large theaters and schools.

Buildings where valuable goods and important documents are kept, and buildings where hazardous materials are stored.

Components of lifeline networks, whose failure would cause the entire system to be put out of service, for example intake and water treatment plants, trunk pipelines, energy generation plants, key transformer patios, important bridges, telecommunication key centers, etc.

Average: Apartments, offices and shops, hotels and industrial facilities.
Lifeline components whose failure may only affect limited zones or which may be substituted by redundant elements.

Low: Constructions with low occupancy or buildings where low-cost and non-hazardous materials are stored, and it fail do not affect other facilities.

TABLE 1

SITE HAZARD DEGREE & IMPORTANCE AND FUNCTIONS OF CONSTRUCTION

SITE HAZARD DEGREE	CONSTRUCTION IMPORTANCE AND FUNCTIONS		
	a) IMPORTANT	b) AVERAGE	c) LOW
1) High	Not permitted, but in exceptional cases if supported by comprehensive site investigation, with sound engineering solution and evacuation plan	The same as 1a).	Permitted, but some site investigation is needed to choose the best possible location for the installation. An evacuation plan is needed
2) Moderate	Detailed site investigation is recommended to select the best location for the facilities and to reduce construction cost.	Site investigation according to normal engineering practice	A quick site investigation is needed and some disaster mitigation measures.
3) Low	Ideally the best location for important constructions. Site investigation according to normal engineering practice.	The same as 2b.	On site, minimum mitigation measures are recommended.

6. FORCES ACTING UPON CONSTRUCTIONS

Table 1 - Site Hazard Degree & Construction Importance and Functions of Construction may be used as a general guide to determine the forces acting upon constructions.

6.1 In case of very violent phenomena such as flash floods or volcanic lateral blasts, it is unpractical and too expensive to try to take with construction strength the tremendous forces generated by such events.
So it would seem rational to avoid sites with high hazard degree for important and average constructions.

However since in some cases, a comprehensive investigation including the upper basin of a river valley, needed to be used for the design of an important bridge, may provide the necessary information to locate it high enough so that flash floods and mud-flows with given return period, may provide enough space to flow under the structure, not damaging it. This is one example, that illustrates the concept of Table 1.

6.2 In addition to dead and live loads in earthquake prone regions or those subjected to high winds, the forces generated by these phenomena need to be considered, but shall not be assumed to act simultaneously.

A site investigation which includes regional and local studies may provide the necessary information for a modern earthquake and wind code. For example from existing seismicity data, it is possible to obtain the seismic zone coefficient and local geotechnical investigation gives the soil coefficient. In the same way, the minimum basic wind speeds may be obtained from a regional study or from existing maps; and the local topographic data together with the size and shape of the structure will give the combined high, exposure and gust factor coefficient.

6.3 In areas threatened by snow or volcanic ash, flat roofs must not be used, and adequate slope and strength are to be given to the roofs.

Note: Most countries have well established and detailed load specifications. These recommendations do not seek to change those specifications, but made aware engineers and planners that it is rational to avoid important construction at high-hazard sites as defined in 5.1, unless a comprehensive site investigation is carried out, and sound engineering solution is provided.

7. EARTHQUAKE CONSIDERATIONS IN SPECIAL CASES

7.1 Adobe housing is not permitted in high hazard sites or subjected to any type of floodings. It is recommend that earthen housing be use only on the sites with moderate to low degree of hazard. A continuous tie beam located at the upper border of doors and windows has proved to be a very effective element to take flexure solicitations, where walls are subjected to horizontal vibrations. (Kuroiwa, 1992b)

7.2 Masonry constructions with balanced wall density in the building's two main directions, and the use of reinforced concrete columns and tie beams substantially reduce the earthquake damage.(Kuroiwa and Kogan 1980)

7.3 A sound structural setting to take horizontal seismic forces, including symmetrically located shear wall-in plant, and with no sudden change in elevation, may be the most economical and rational solution for reinforced concrete buildings.

Structural analysis methods, lateral drift control, structural and non structural elements design, the need for supervision, etc. are included in earthquake resistant codes and regulations of 37 countries edited by the International Association for Earthquake Engineering in 1992. (IAEE, 1992)

8 MICROZONATION AND LAND-USE PLANNING FOR DISASTER MITIGATION

To achieve a safe an orderly expansion of urban conglomerates a key tool is a microzonation investigation. In the study all natural phenomena threatening the area of interest are included: earthquake, flooding, soil failure, volcanic activity, etc. Then the area is divided into sectors offening different degrees of hazard.
The safest sectors are designated for the most important urban components such as high density, residential areas and try to locate there important constructions as defined in 5.1 and Table 1., and the most hazardous sectors for parks and similar uses. (Kuroiwa and Alva, 1992).
The methodology is being applied in Peru's National Progam for Disaster Mitigation - PNPDM, the country's main activity for the IDNDR. It was used from 1989 to 1992 in Peru's northernmost Grau Region (Kuroiwa et al., 1992a) under the auspices of the Japan Internacional Cooperation Agency - JICA and from 1992 to 1995 in

Peru's southwestern region, where a seismic gap is said to exist. The funding was mainly provided by the Canadian Internacional Development Agency - CIDA, and the project was developed by the Department of Humanitarian Affairs of the United Nations - DHA/Geneva and Peru's Civil Defense - INDECI (Kuroiwa, 1995) (Kuroiwa and Zupka, 1996). The institution heading both projects was CISMID, the Japan-Peru Center for Earthquare Engineering Research and Disaster Mitigation belonging to the Department of Civil Engineering of the National University of Engineering (UNI) Lima, Peru. The active participation of the local universities was encouraged, to transfer the technology received by CISMID and techniques developed there.

Microzonation and its application to urban and regional development planning for disaster mitigation is being disseminated through the so-called Third Country Seminars for Latin American participants organized by CISMID and JICA. Seven such events have been held in Lima, Peru, since 1989.

Lifelines are spread all over the cities, some elements are continuous as pipelines and their key components are known, so a wise land use planning taking as a base a microzonation map may be very much beneficial to reduce damage during future extreme natural events.

For important constructions located outside areas covered by microzonation studies an special and detailed site investigation is needed.

9 CONCLUDING REMARKS

By reconciling man's activities with the lessons learned from past natural disasters, it is possible to reduce drastically the number of victims and the amount of loss produced by future phenomena of the types discussed.

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