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GIS TOOL FOR CALCULATING REPAIR COST OF BUILDINGS DUE TO EARTHQUAKE EFFECTS (CCRE - CISMID)

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Abstract: In recent years, in the Peru, had the bad experience of having suffered many human and material losses due to the effects of natural disasters, particularly earthquakes. These effects are more frequent and mostly grow in number of people and affected property, this is due to the development of cities, especially in the Peruvian coast. In the Peru the development of cities is not in an orderly and planned way and people built their houses without following the current regulatory framework that ensures good structural behavior during the event of the occurrence of a severe earthquake. For reasons previously needed a tool that allows the identification of areas that are at high risk to take adequate measures to prevent and mitigate the effects of a severe earthquake. This study presents a system automated on a GIS platform, which allows to know the likely effects of an earthquake in an urban area, taking as a basis the Geotechnical information place, urban cadastre and creating a numerical model of seismic response for different building types commonly used in Peruvian territory. This tool will be granted to government entities as a consultation and generation of information base for their development plans.

1. INTRODUCTION

In the past years we have suffered great earthquakes in Peru that have brought high damage in urban areas causing not only material damage but also human loss. To make a recount in 1996, 2001 and 2007 the southern part of Peru have suffered from the consequences of earthquakes with magnitude near or greater than Mw = 7.5 that have devastated a large area of many populated areas.

Since these recent seismic activities Peruvians have acquired awareness about the importance of prevention activities specially regarding on building earthquake resistance.

All these reasons make the necessity to develop a practical tool to identify the vulnerable urban areas due to effects of a big earthquake. This tool is based in three aspects: Seismicity of the area, soil conditions and structural characteristics of the buildings.

The digital environment for the development is the ArcGIS v10.0, suite in which it is possible to develop customized applications for any kind of geospatial information. The language that have been used to develop the tools if Python.

In this work it has been developed a tool to evaluate basically two things: The number of ruptures in a water distribution network and the replacement cost of the building in terms of percentage of the total cost of the building state before the earthquake.

2. REQUIRED DATA

As mentioned before the developed tool is based in soil conditions and structural characteristics of the buildings and construction material for pipes.

2.1. Soil conditions

The soil conditions are classified according to the Technical Standard E 03 for Earthquake Resistant Design, where the Peruvian territory is divided in three seismic zones, and a Zone Factor can be obtained. Then it is required a geothecnical study, where the soil is classified in four types according to their competence to resist loads and dynamic behavior in an occurrence of an earthquake. The soil factors for each type of soil are shown in Table 1:

Table 1. Soil amplification factors (Peruvian National Code)

Soil Type	Description	Amp. Factor
S1	Rocks	1.0
S2	Intermediate	1.2
S3	Soft soil	1.4
S4	Special case	To be determined

For soil Type S4 it is necessary a better study to determine accurately the amplification factor. For example this is the case of refilled soils. Other parameters related with the soils conditions is the seismic amplification factor, that relates the soil period and the structure period, this value is equal or less than 2.5. To apply these soil factors, first it must be calculated the acceleration on the rock by making a seismic hazard assessment of the area under study and then apply these amplification factors to obtain the acceleration in the base of the building.

2.2. Building characteristics

To analyze the building seismic response it is necessary to know few physical parameters of them and put them in a geo-database. The geo-database is a compilation of two groups of information. On one side, the cartographic information, it means the location, size and shape of the lots, and the other one is the database where it is kept the descriptive data of each building.

The descriptive geo-database that contains the information on the lots is based on the cadastral information shown in Table 2:

Table 2. Building related database.

Field	Value	Description
Use	0	Empty
	1	Individual House
	2	Multifamily House
	3	Commerce
	4	Public buildings (School, Hospital, Police)
Material	0	Empty
	1	Adobe or quincha
	2	Masonry
	3	Reinforced concrete
	4	Others
Conservation	0	Empty
	1	Good
	2	Regular
	3	Bad
	4	Very bad
Height	Number	Number of stories

If the cadastral information is not available, it is necessary to make a field survey. This field survey can be made at different levels: a) Lot level, each lot is investigated and its data fills one registry in the data base. b) Block level, the data is only one registry per block, it means that only one building in the block is evaluated, this is the representative lot. The criteria to select the representative lot depends on repetition of the values shown in Table 2, for example if in one block there are building of one, two or three stories, and the majority of buildings have 2 stories then this is the value that is considered as the representative. c) Sector level, if the resources to make a field survey are very limited, then it is taken a sample data from the total population. This procedure is very valid since the people from the same social and economic class build their houses almost as the same way, the properties of these building can be generally represented for one model and the value assignation is the same as for blocks.

To evaluate the damage in the buildings fragility curves were developed based on data that was obtained from the study made at CISMID with the following procedure:

a) Calculate the natural period of the building by means of Eq. (1) and Eq.(2)

$$t = 0.07H(1 + 0.75z/981) \quad (1)$$

$$f = 2\pi/t \quad (2)$$

Where:

$t =$ Period

$H =$ Height of the building

$z =$ Base acceleration

$f =$ Frequency

b) Calculate the distortion of the building

$$d = 1.75(0.75du)(z/f\hat{}2)\,/H \quad (3)$$

$Where$:

d =Distortion of the building

du =Ductility of the building (2.5 in case of masonry)

c) Calculate the damage ratio based on the distortion

This distortion of the building can be related with the level of damage by means an empirical curve. This empirical curve has been developed by analyzing the seismic response of different masonry buildings in Lima city, by carrying out a numerical simulation and obtaining different level of damage. Finally, these values are averaged to obtain a regression curve that relates these two parameters: Damage vs. Distortion, shown in Figure 1.

From this empirical curve a regression line is calculated and it is obtained the relationship between distortion and level of damage that is shown in Eq. (4)

$$ld = -13287d^2 + 204.61d + 0.0014 \quad (4)$$

Where:

$ld =$ Level of damage

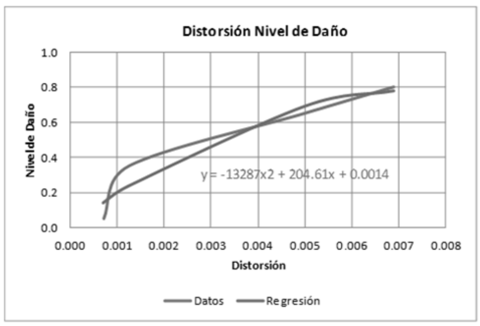

Figure 1. Empirical relationship between Distortion and Damage level, for masonry building at Lima City.

2.3. Water Network characteristics

In case of the water network system, also it is necessary to know the location of the pipes to be intersected with the soil conditions and two descriptive parameters: The diameter and the material of the pipe.

The damage parameter that is evaluated in case of water distribution pipes is the number of breaks per kilometer of pipe. Some studies have investigated that the number of breaks is related with the velocity of wave propagation during an earthquake, therefore it is necessary to convert the soil acceleration into velocity. From the studies made at CISMID (2010) a relationship between acceleration and velocity has been obtained for Lima soils. This relationship is shown in Eq. (5)

$$v = 11.504e^{0.0045z} \quad (5)$$

Where:
$v =$ Soil velocity
$z =$ Soil acceleration

The number of breaks per kilometer in case of asbestos-cement or PVC is shown in Eq. (6):

$$nr = -0.0000005v^3 + 0.0002v^2 - 0.0029v \quad (6)$$

Where:
$nr =$ Number of breaks per kilometer of pipe
$v =$ Soil velocity

3. TOOL DEVELOPMENT

The goal of this informatics tool is to systematize all the information related with soils, buildings and water pipes to prepare thematic maps that can be used for making decision people as a tool for disaster prevention and mitigation plans.

The systematization is developed in a geographic information system platform as a customized application by programming by using Python language. To develop this system was necessary to follow the flowchart shown in Figure 2 to verify the data consistency and to pass to elaborate the suitable program.

The steps to develop the tool are:

a) Requirement definitions: In this step all the necessary information is verify if exist or not. If the data does not exist then it is necessary to create it, by conducting field survey or bibliographic search. As was mentioned before the level of detail depends not only on the existence of the data but also on the budget to get it.
b) Data search and analysis: In this step the acquired data is verified, quality, quantity and possibility of use is confirmed. If some data is missing a field survey is conducted to fill out the missing information.
c) Building and water pipe models: With the formulas and equations shown above the assessment damage models are developed. The results are compared with the previous results and if there is any correction it is made to accomplish the determined accuracy.
d) Development of GUI: The Graphical User Interface is developed to interactively select and enter the data to the system. In this section dialog windows are develop to select soil, building and water pipe files. The files must be in SHaPe format, to be compatible with the system. Also all shape files must be in a same geographic projection to carry out the intersection process between layers. This requirement must be verified before the shape files are used.
e) Application: After the data is verified and calibration process was done the tools is applied to real data to obtain the thematic maps, where different presentations are possible to obtain. These thematic maps will allow to the users to make statistical analysis.

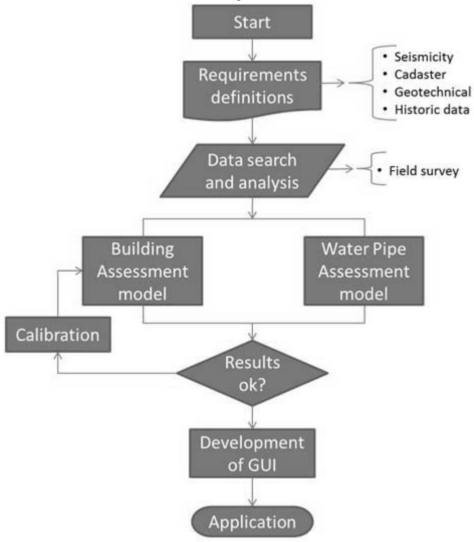

Figure 2. Flowchart to develop the informatics tool.

4. APPLICATION

As mentioned before, the application is developed by programming in Python language within the platform of the commercial software ArcGIS. The version that must be used to run the application is v10.0 or later with service pack 3 installed. The modules used in Python are Arcpy and Math to call routines and functions that are already written and developed to be used in ArcGIS platform.

It is important that all the information and programs must be in a common directory as shown in Figure 3.

Figure 3. Location of Data (Origen) Output Folder (Procesamiento) and Programs (Programas)

Once within the ArcMap platform this directory must be connected to access the data and programs as shown in Figure 4.

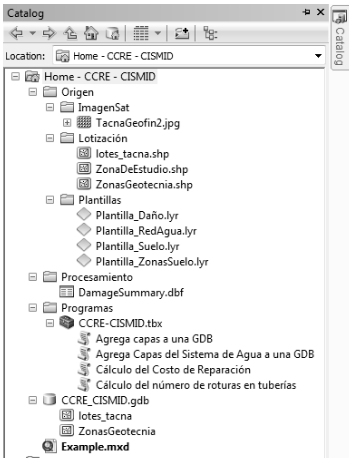

Figure 4. Access to working directory.

Application to Tacna City

As an example the system is applied to Tacna city in southern Peru. It was applied here since there were the necessary to data: geotechnical, buildings and water pipe.

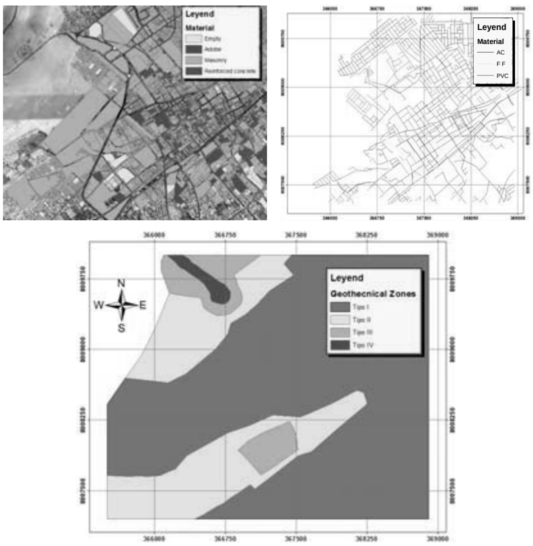

Figure 5. Integrated data: buildings, water pipes and geotechnical.

With this data the program is run and finally it gives the thematic maps with the level of damage in buildings and water pipes. Figure 6 shows the thematic map of level of damage for buildings in Tacna city.

5. CONCLUSIONS

- An automatic tool to evaluate the building and water pipe damage has been developed.
- To carry out the damage assessment procedure geotechnical, cadastral and pipe information is necessary. However, the building information could be in different area sizes: Lot, Block or Zone, depending the quantity or quality of the data.
- The tools can be applied to cities with similar building, pipe and soil conditions similar to Lima city.
- To obtain empirical relationships between acceleration and level of damage, it has processed a wide variety of cases, so the application is well calibrated for this type of buildings and soils.
- Regarding the analysis for water pipe some additional curves may be develop, to cover the variety of pipe materials and diameters, but this tools can give a good figure about the possible damage in case an severe earthquake.
- Statistical information can be obtained from the final thematic maps and can be used to make prevention and mitigation plans.

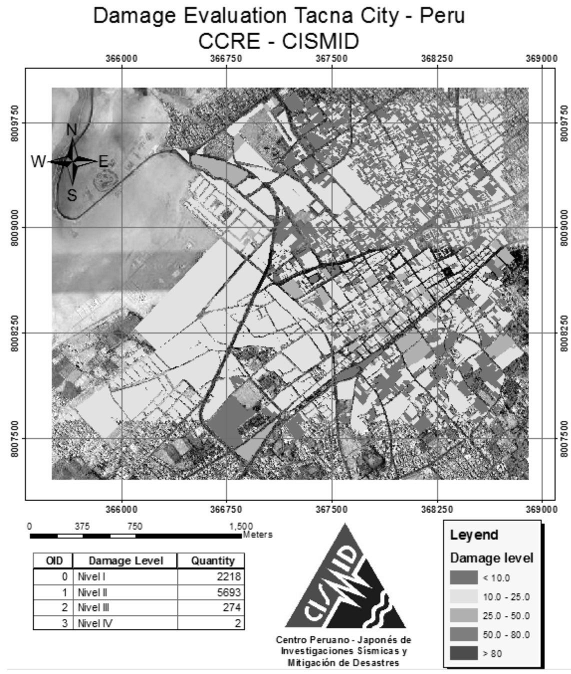

Figure 6. Integrated data: buildings, water pipes and geotechnical.

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