Methodology to determine the amount and composition of construction waste from collapsed buildings

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Introduction

The occurrence of earthquakes is unpredictable. Therefore, it is not possible to predict when they could happen. However, the places in the world with the highest seismic activity have been identified. Figure 1 presents the seismic activities regions in the world (Time, 2017)

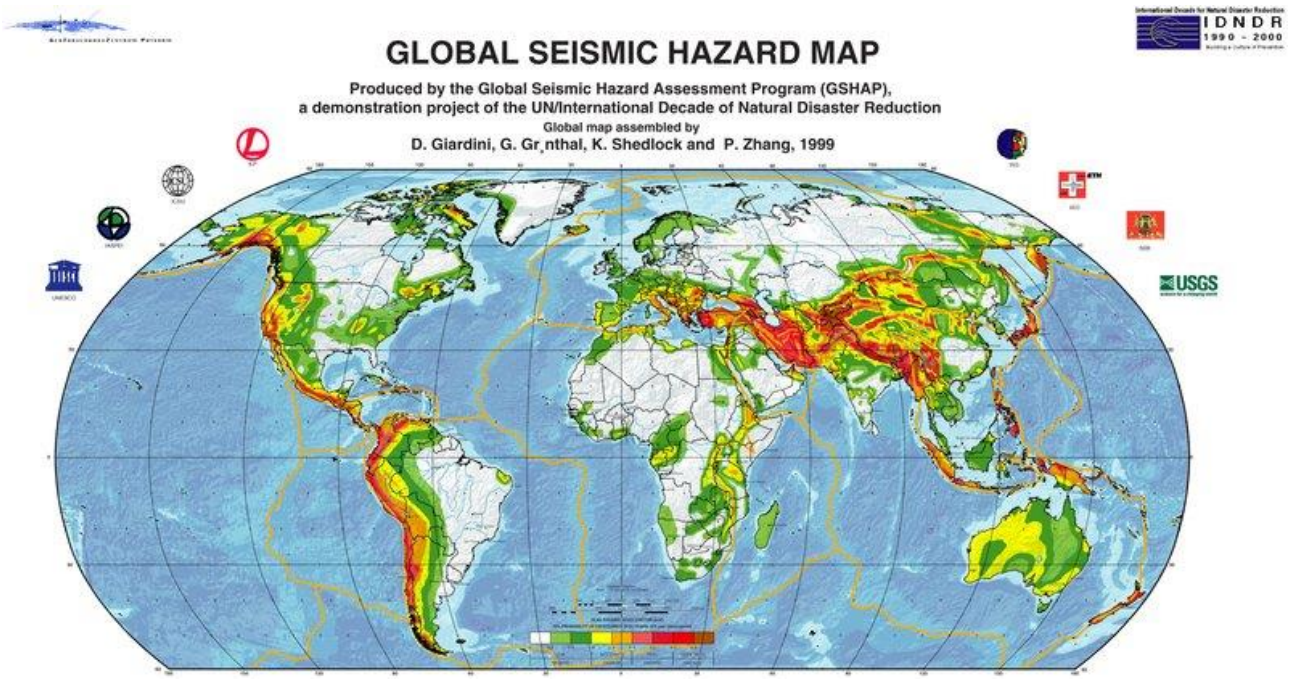


Figure. 1 Global seismic hazardous map (Time, 2017)

Mexico is located in the context of five tectonic plates: Caribbean, Pacific, North America, Rivera and Cocos. The last two plates are submerged under the North American plate (Fu Wang et al, 1998). Figure 2 presents the hazards of seismic activity in Mexico. Recently two important earthquakes happened in Mexico: the first one on September 7, 2017 with magnitude 8.2 located in the vicinity of Pijijiapan, in the state of Chiapas and the other one on September 19, 2017 the (SSN) reported an earthquake with a magnitude of 7.1 located in the state boundary between the states of Puebla and Morelos (NSS, 2017). As a result, 110 thousand buildings were damaged in Oaxaca and Chiapas. The September 19 earthquake affected Mexico City where 3,848 buildings were structurally damaged and 52 of them collapsed. Because of a lack for adequate procedures to manage construction and demolition waste in Mexico, in this paper a Methodology to determine the amount and composition of construction waste from collapsed buildings was developed.

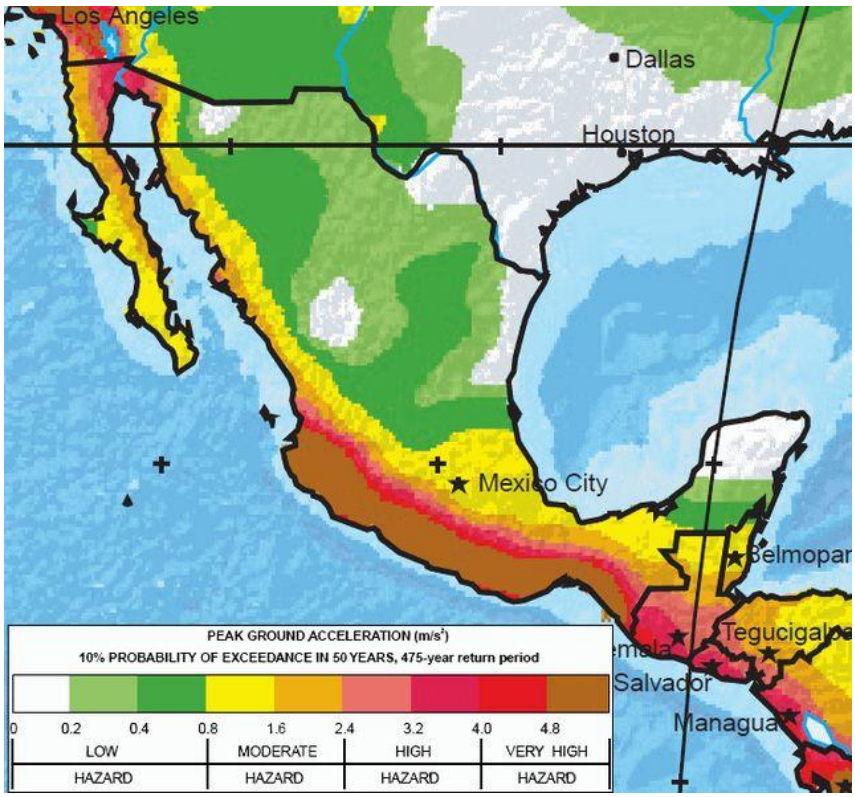


Figure 2. Hazard of seismic activity in Mexico

Objectives

To develop a methodology to determine amount and composition of construction and demolition waste, C&DW, in case of a disaster due to earthquakes.

Material and methods

1. **Bibliographic and documental research**

   Most of international bibliographic on Construction and Demolition Wastes, C&DW, management are oriented to normal or daily construction activities such as:

   - Source reduction
   - Recycling and re-use
   - Deconstruction
   - Collection
   - Transport
   - Disposal of

These practices normally are planned and several entities and actors participate: owners of the buildings, constructors, municipal authorities, public and private enterprises. Moreover, in developed countries, C&D wastes represent an important economic activity and care of the environment is considered.

However, when a natural catastrophe happens, such as flooding, hurricanes, tornadoes and earthquakes, there is insufficient information on criteria and methodologies for environmental management of construction and demolition waste in contingencies.

2. Classification of buildings for the magnitude of damage occurred

When a strong earthquake occurs, magnitude above of 6 of Richter scale, the probability of collapsed buildings is high. Table 1 shows Ritchter´s scale for the occurrence of an earthquake.

GRADE	EFFECTS
LESS THAN 3.5	Generally, is not detected, but registered.
3.5 – 5	Constantly noticed, but only causes minor damages.
5.5 – 6.0	Causes light damages to buildings.
6.1 – 6.9	It can cause sever damages in populated areas
7.0 – 7.9	Major earthquake. Causes grave damages.
8 OR HIGHER	Great earthquake. Total destruction of close communities

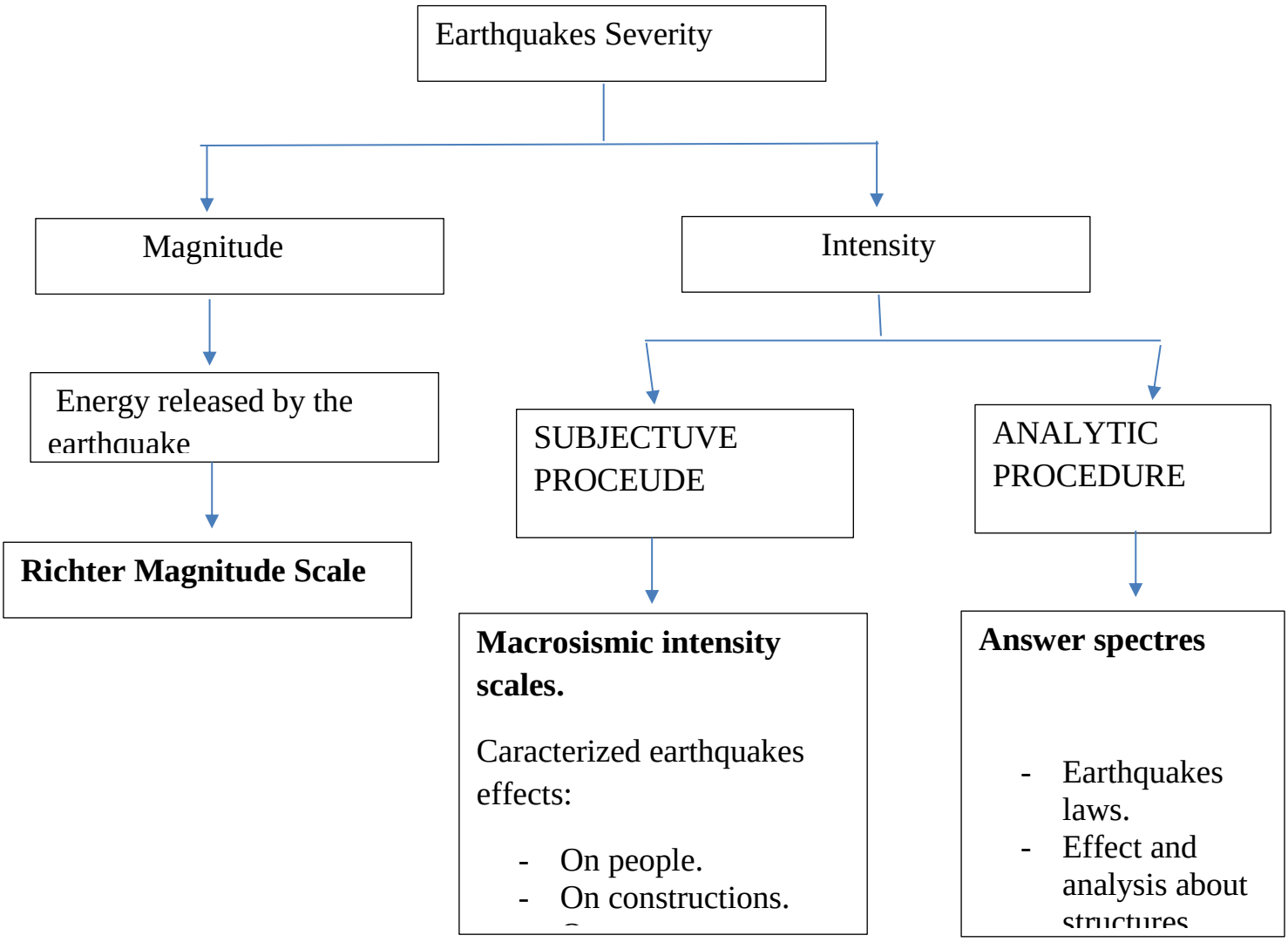
Table 2 shows the effects on people and objects after an earthquake considering the grade of these phenomena.

Table 2. Effects on people and objects according the grade of an earthquake.

GRADE	EFFECTS ON PEOPLE AND OBJECTS
I **NOT DETECTED**	- Any effect is detected
II **BARELY DETECTED**	- Vibrations can be detected by a few people (1%), specially resting people or on the high floors in a building.
III **WEAK**	- Some people inside a building note the earthquake. - People resting feel balanced or a little shake. - Hang up objects lightly swing.
IV **HIGHLY OBSERVED**	- The earthquake can be noticed in the inside by many people, but in the outside by a few. Some people may wake up. Vibration levels are not that alarming. Windows, doors and plates can scratch. Hang up objects swing.
V	- Almost every person inside a building can notice, but outside just a few. Many people who were sleeping wake up and runout from the buildings.

STRONG	- Hang up objects swing. - High positioned objects fall. - Doors and windows are open and closed by themselves.
VI **SLIGHTLY** **HARMFUL**	- Noticed by everyone inside a building and by many people on the outside. People scare and runout. - Little objects fall down. - Little damage in old buildings, such as cracks.
VII **HARMFUL**	- Most of the people scare and runout to the outside. - Furniture is moved and objects from shelfs fall down. - Many old buildings can suffer damages.
VIII **GRAVELY** **HARMFUL**	- Difficult to stay on your feet, even inside or outside. - Furniture may knock over; objects such as televisions and type machines may fall down. - Can find rippling in soft lands.
IX **DESTRUCTOR**	- General panic. - People may be roughly lashed to the floor. - Monuments and columns fall down or roll. - Soft lands are rippled.
X **VERY** **DESTRUCTIVE**	- Old buildings collapse.
XI **DEVASTATOR**	- Almost evert old building is collapsed.
XII **COMPLETELY** **DEVASTATOR**	- Earthquakes effects reach the maximum effects accepted. - Structures above and underground are gravely damaged or destroyed.

In figure 3 it is presented a flowsheet of Magnitude and Intensity of an earthquake.



In Table 3 it is presented a method to classify damaged buildings based on the level of damage. Mexico City authorities used this classification after 19th July 2017 earthquake.

Table 3 Classification of damaged buildings in the occurrence of a natural disaster

Category	Significance	Requirements	Affectations
Green	Minor damages	Minor repairs	Building may be used
Yellow	Significant non-structural effects	Major repairs	Building can not be used during repair
Red	Major damages	Demolition	Inhabited

Buildings in the "green" category have minimal effects and are still habitable as it is ejemplified in figure 4.

Figure 4. Building classified with Green color

The buildings classified with "yellow" color show moderate damages; they require major repairs and can not be used by their owners during the repair period. Figure 5 presents an example of a building classified as yellow color.

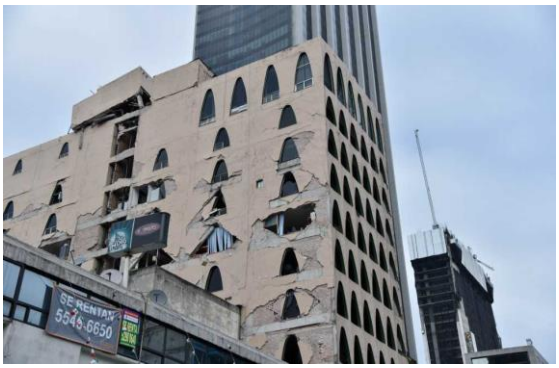


Figure 5. Building classified with Yellow color

On the other hand, the buildings classified with "red" color, almost collapsed, they necessary have to be demollished. In figure 6 a building classified as Red color is presented.

Figure 6. Building classified with Red color

In Mexico City the authorities reported 10 thousand buildings of "green" color, between 2 thousand and 3 thousand buildings of "yellow" color and around 500 of "red" color after the 19th September 2017 earthquake. Figure 7 shows a map presented by Mexico City authorities of damaged buildings.

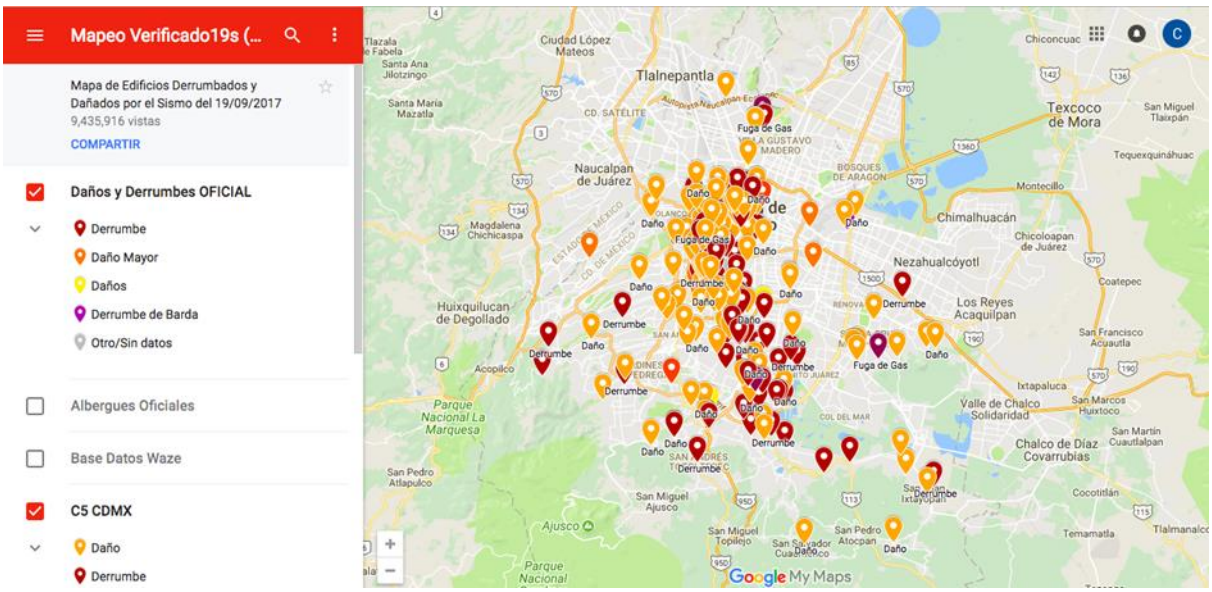


Figure 7. Damaged buildings after 19th September 2017 earthquake in Mexico City.

3. Method to quantify the amount of C&DW

Next, an easy method to quantify the amount of C&DW is presented. It is based on the following parameters

3.1 Location of the damaged buildings

This fundamental step can be done by several ways:

a) Reports of inhabitants
b) Video cameras in the streets
c) Satellite photographs

3.2 Inspection of damaged buildings

It is necessary to inspect and check damaged buildings after they were located in a map.

3.3 Compilation of building information

Persons in charge to attend damaged buildings have to gather minimum information and data of these structures to estimate as follows:

- Number of building floors
- Constructed surface
- Surface of each floor
- Volume of each flat
- Average specific weigh

To illustrate a simplified method to estimate the amount of C&D wasted, it is presented an example in point 4.

3.4 Example

Determination of the amount of Construction and Demolition Waste after a collapsed building.

Data:

•Number of floors: 8

•Dimensions of a floor: width → 20 m, length → 15m and height → 3m.

Considerations:

1. Volumetric weight of concrete 2 400 kg/m3

2. Percentage of structural volume 10%

3. Percentage of furniture and appliance volume 30%

Volume of wastes:

a. Concrete

b. Furniture and appliances

Solution.

Floor volume: w*h*l = (20 m) (15 m) (3 m) = 900 m^3 per floor.

Which give us a total volume, for the 8 floors, of 7200 m^3.

For each floor, we will have 90 m3 of concrete volume, as it is the 10% of the total floor volume, and considering the 8 floors we have a total volume of 720 m3. Expressed in weight, we have 216 000 kg or 216 tons.

Now, as we have the 30% of the floor occupied by furniture and appliances, the volume of these appliances will be of 270 m3 per floor. Which give us a total furniture volume of 2160 m3.

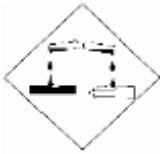
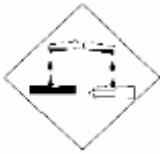
4. **Methods to identify and classify residues.**

4.1Classification in groups: hazardous, non-hazardous, recyclable, and disposable waste.

Waste generated by collapsed buildings due to earthquakes such as the one that occurred in Mexico City on September 19th of last year, are temporarily stored in inappropriate places and without any planning or care to avoid environmental impacts and risks to the inhabitants health.The composition of this waste, unlike the waste generated in the construction of buildings under normal or regular conditions, also includes the HDW such as: automotive maintenance (spent lubricating oil, brake fluid, antifreeze liquid); Products for cleaning and maintenance of the home (liquid plunger, solvents such as thiner and turpentine, glues and epoxy adhesives) insecticides, herbicides, rodenticides and medical care residues (punches, venoclisis and healing material) that may endanger the health of the inhabitants victims who live temporally in camps or even the workers themselves. On the other hand, if the storage time is prolonged, the occurrence of rain produces leachates that drain on the sidewalks and streets that can affect the pets that drink water and people who accidentally come in contact with those liquids that can cause them skin damage or stomach infections as well as environmental impacts to air, soil and water

As part of an environmental and beneficial management of C&D wastes after collapsed buildings, it is necessary to classify them in a form to ensure minimum negative impacts to human health and to environment. A classification for environment protection can be on Hazardous and not hazardous wastes. Many countries in the world specify in their laws or normativity hazardous domestic wastes, HDW, which have to be handled with special care. In Mexico City exists a local law that classify Domestic Hazardous Wastes (Sedema, 2015) In table number 4 it is presented a list of DHW that are included in the local legislation.

Table 4. Domestic hazardous wastes**.**

Material or container	Products	Actions
Automobile maintenance: Empty container, or with waste, and the sub products that this waste have contaminated, such as: impregnated tows or rags, fuel and oil filters	- Engine oil. - Warn-out lubricant oil. - Fuel additives. - Antifreeze liquid. - Engine cleaner. - Carburetor cleaner. - Acid-lead batteries. - Fuels. - Transmission liquid. - All those products in which cases you can see these symbols.  Figura 1  Figura 2	Wastes that are included in this list must be delivered to the specific Management Plans responsible authorized by *Secretaría del Medio Ambiente y Recursos Naturales*, or through the programs established for this effect by the Secretary, and the politic Delegations.
Home cleanliness and maintenance products: Empty container, or with waste, tows, impregnated rags, brushes, sponges, rollers, etc.	- Liquid plunger. - Metal cleaner and polishing products. - Tartar removers. - Solvents (turpentine). - Epoxy glues. - Paint and varnish removers. - Sealers. - Wood ink. - All those products in which cases you can see these symbols.  Figura 1  Figura 2	Wastes that are included in this list must be delivered to the specific Management Plans responsible authorized by *Secretaría del Medio Ambiente y Recursos Naturales*, or through the programs established for this effect by the Secretary, and the politic Delegations.

Biocides: Empty container, or with waste, and the sub products that have been contaminated.	- Wood keepers. - Insecticides. - Weed-killers. - Naphthalene in all its presentations. - Rat poison.	Wastes that are included in this list must be delivered to the specific Management Plans responsible authorized by *Secretaría del Medio Ambiente y Recursos Naturales*, or through the programs established for this effect by the Secretary, and the politic Delegations.
Medical and health assistants.	- Expire medicines for people and pets. - Puncture stuff and recovery materials.	Wastes that are included in this list must be delivered to the specific Management Plans responsible authorized by *Secretaría del Medio Ambiente y Recursos Naturales*, or through the programs established for this effect by the Secretary, and the politic Delegations.
Various.	- Batteries made of mercury, nickel or zinc-silver. - Asbestos. - Explosives. - Fluorescent lamps. - Energy-saver lamps. - Photographic material. - Chemical products for pools. - Hair color.	Wastes that are included in this list must be delivered to the specific Management Plans responsible authorized by *Secretaría del Medio Ambiente y Recursos Naturales*, or through the programs established for this effect by the Secretary, and the politic Delegations.

In addition, C&DW can be classified in recyclable and disposable wastes. Materials like clean concrete, wood, metals, glass and among other materials can be separated for reuse and recycling.

5. Guidelines for an adequate management of C&DW

In this part, it is presented some guidelines to make a suitable management of C&DW in disaster conditions:

- **Site Inspection**

The first step to start with the construction and demolition waste management is to know the site in which the disaster has occurred. It is also necessary to ask for the information of the building, for example, what was the purpose of the building. If there were offices or it was a school or any other type if building that we can have, to know and suppose the type of waste that the building should generate.

- **Separation and classification.**

It´s the process that describes the actions or procedures to classify specific components or materials to start the separation. Special or hazardous waste must be managed in a special way. There must be a specific place in the site to separate and classify the different materials and to exclude all those residues that may need special attention. It is necessary the use of security equipment and signs. In this step the decision of the next move is made, here you have to choose whether the material is reusable, hazardous or can be delivered in a landfill.

- **Temporary Storage**.

Waste storage must be based in the insurance of environmental and human health protection, and in the compliance of the corresponding laws. This activity is, if possible, executed in the generation site. Storage can be made in cases or boxes made specially with this purpose, which specific characteristics will depend on waste´s type and volume that is going to be stored in each container.

In some cases, materials can be stored and classified as recyclable material, landfill material, or reusable materials.

- **Separated Collection.**

As we already have all the materials classified and separated, we have to make sure that when we collect the waste to transport it to wherever it has to, the waste cannot be mixed up again. This will make our delivery much easier to the site that corresponds to each type of waste found.

- **Transport.**

Transport to the final disposal site or reuse and recycling places, must be applied under the strictest security, environmental and ethic regulations.

Waste transported from the demolition site to a landfill will be those that were rejected as reusable material that can be used in other projects, or the ones that, because of its characteristics, it cannot be recycled. Therefore, to landfills, the only material that is transported is the one considered trash.

The transport method will depend on the company´s politics. In most of the cases, constructive companies own trucks that can transport the material, or else the companies hire special transport business that do this step. It is importance to make sure that the material is getting to the right place.

- **Reuse and recycle.**

The reuse and the possibility of valorization for reutilization or recycle of construction and demolition waste will depend on the individual material markets and the ability separate them from other materials. Materials that are more commonly found and that can be reused or recycled can be described in three groups:

- Materials made of cement, lime, sand, concretes and blocks of concrete.
- Ceramic materials, such as tiles, tubes, bricks.
- Materials that can be recycled or co-processed in other industries such as wood, metal, gypsum, soil, paper, plastic, organic Materia, glass.

There are important advantages in terms of ecology, because recycled waste can substitute traditional aggregates that come from natural reserves, which many times are devastated thanks to the extraction activity. There is also the possibility to recycle the debris in the same demolition site, after being correctly grinded.

It is highly recommended the keep updating about programs that allow knowing which are the materials that can be reused or recycled, the appropriate equipment for collection and transport, and all the necessary information about reuse and recycle of construction and demolition waste.

- **Final disposition sites.**

Based on the local laws, the generated construction and demolition waste management, including its final disposition, must be authorized by the authorities, which will provide all the information that is needed.

This guideline considers the next sections:

1) Location of final disposal sites.
2) Operation of the final disposal sites.
3) Use and recycle of construction and demolition waste.
4) Sanitation and closing of final disposal sites.

1. - Location of final disposal sites and temporary storehouse.

Although we know that construction and demolition waste are considered motionless materials, it is important to remark that in an earthquake (emergencies or any natural disaster), these types of wastes can be contaminated by other wastes such as paint, metals, home cleaning products, etc. Now we list the restrictions that must be considered to have a good final disposal site:

- Do not locate sites in natural protected areas, ravines, mangroves, swamps, estuaries, rainless flatland, caverns, faults or geological failures.
- The final disposal site should be located away of inundation zones.
- Final disposal sites must be, as minimum, as 500 meters away from water bodies like lakes or lagoons.
- It is preferred to locate the sites in a range no bigger than 25 Km away from the center of the disaster zone.
- Must consider sites where the landscape has been deteriorated, such as mines, quarries, and places where water is not close. Consider less productive grounds.

2. - Operation of final disposal sites and temporary storehouses.

Landfills are not the best sites to use to dispose of construction and demolition wastes generated by earthquakes, because the volume of theses wastes is great. Landfills are designed to operate with municipal solid wastes, not with demolition and construction waste, so these last wastes can take down the infrastructure of the landfill.

However, if it is necessary to make use of a landfill for construction and demolition wastes, it should be guaranteed that the different types of wastes are not going to mix up.

Next, a list with the standard actions that must be considered for the operation of final disposal sites of construction and demolition wastes after an earthquake:

- Wastes should be deposited in order as slopes in the site, taking care of the stability.
- Every site must establish a control at the site´s entrance and a register mechanism of every material introduced to the site.
- It is not allowed to deposit materials that could be contaminated by toxic, hazardous and liquid waste.
- The size of the sites must be planned according to the volume of construction and demolition wastes.
- The final disposal site must count with hydraulic constructions that allow the correct drainage. Also, with receiving wastes schedule to prevent noise contamination and special signs at the site´s entrance to prevent accidents.
- Actions of watering must be with dirty water, just to prevent dust emissions.

3. - Use and recycle of construction and demolition waste.

Considering that, the total of demolition waste can be used through recycling to obtain rocky materials that can be applied in next constructions.

Now a list is presented naming the actions to use and recycle wastes.

- Establish a separate manage of the construction and demolition waste.
- Try not to contaminate with other waste such as textiles, plastics, wood, glass, metals, organic waste, etc.

4. - Sanitation and closing of final disposal sites.

Once the activity and the useful life of the final disposal site of construction and demolition waste caused after a natural disaster is finished:

- The site should be prepared to whatever the site is going to transform to, it could be sport or green areas.
- Establish a maintenance program of superficial drain.
- Establish a series of programs talking about activities to recover the site.

6. Conclusions

1. In Mexico there is not procedures for an adequate management of C&DW in cases of disasters due to earthquakes
2. Environmental problems and human health could occur due to an inadequate management of hazardous waste present in C&DW
3. As part of an environmental and beneficial management of C&D wastes after collapsed buildings, it is necessary to classify them in a form to ensure minimum negative impacts to human health and to environment.

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