Nature of Earthquakes

Elements of Seismology and Earthquake Engineering

Roberto Tomasi

11.05.2017
Overview

1. Learning from Earthquake
   - What is an Earthquake?
   - What is Earthquake Engineering?
   - Learning from past Earthquakes

2. The Nature of Earthquakes
   - Focal mechanisms and seismic waves
   - Plate tectonic theory
   - Seismic risk in the world

3. Measuring Earthquake
   - Magnitude and Intensity
   - Historical Earthquake

4. Characteristics of earthquakes
   - Parameters of the model

5. Seismic Risk

6. Conclusions
What is an Earthquake?

- Unpredictable natural phenomenon of vibration of the ground
- It becomes one of the most devastating natural hazard only if it’s considered in relation with structures

«Of course, the problem is the structure under seismic excitation and not the earthquake itself» Chopra A.K.
What is Earthquake Engineering?

- The earthquake has begun to become a problem for humans since they started to build structures.
- The deaths and the damage to buildings that they cause have several economic, social, psychological and even political effects.

A general study of earthquakes involves many scientific disciplines that deal with the problem:

Seismology ↔ Engineering ↔ Economy ↔ Psychology

Earthquake Engineering → Branch of engineering devoted to mitigating earthquake hazards. It covers the investigation and solutions of the problems created by damaging structures.
History teaches...

Northridge (1994)  
U.S.A. - $M_w$ 6.7  
Economic losses: 24 billions $  
Deaths: 57
History teaches...

Kobe (1995)  
Japan - $M_w$ 6.9

Economic losses: 120 billions $  
Deaths: 5500
History teaches...

L’Aquila (2009)  
Italy - $M_w$ 6.3  
Economic losses: 4 billions $  
Deaths: 286
Elastic Rebound Theory

- Earthquakes are ground vibrations that are caused mainly by the fracture of the crust of the earth or by the sudden movement along an already existing fault.
- The fracture or the slippage emits large amounts of energy in the form of seismic waves that travel through the interior of the earth and cross the surface.
- Cracks along which rocks slip are called **faults**; they may break through the ground surface, or remain deep within the earth.
The most common mechanisms of earthquake sources are:

- **Normal faults**: The block above the fault moves down relative to the block below the fault. This fault motion is caused by **tension forces** and results in extension.

- **Reverse faults**: The block above the fault moves up relative to the block below the fault. This fault motion is caused by **compression forces** and results in shortening.
The most common mechanisms of earthquake sources are:

- **Strike-Slip faults**: The movement of blocks is horizontal. This fault motion is caused by shearing forces.

- **Oblique-Slip faults**: Oblique-slip faulting suggests both dip-slip faulting and strike-slip faulting. It is caused by a combination of shearing and tension or compressional forces.
Seismic waves

- The location on a fault where slip first occurs is called the **focus** whereas the position directly above it on the surface is called the **epicentre**.
- **Focal depth** is the distance between the focus and the epicentre. The distance between a site and the epicentre is called **epicentral distance**.

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**Seismic Waves**

- **P or Primary**
- **S or Secondary**
- **Love Surface**
- **Rayleigh Surface**

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The Nature of Earthquakes

Plate tectonic theory

Where do earthquakes happen around the world...

- The stress increases where plates bump into each other, pulling away from each other or past each other.
- Most earthquake occur along the edge of the oceanic and continental plates.
Plate tectonic theory

**Earthquake Events Map**

- California (USA) and New Zealand: Transcurrent horizontal zone
- Chile and Japan: Subduction zone
The nature of earthquakes

In Europe...

- Most of earthquakes occurs in the Mediterranean Area and in Iceland.
- The main reason of the high seismic hazard in the Mediterranean Area is the collision of the African and EuroAsian plates.

European Seismic Hazard Map
[Giardini, Wassner and Danciu, 2013]

Adriatic Microplate
The nature of earthquakes

... in Scandinavia and Italy
The most widely accepted indicators of the size of an earthquake are its magnitude and intensity.
Magnitude and Intensity

Magnitude

- The magnitude is a measure of an earthquake in terms of released energy.
- It does not depend on the epicentral distance or the building damages.
- The most popular at the present time are the Richter Scale, developed by U.S. seismologist Charles Richter in 1935.

<table>
<thead>
<tr>
<th>Class</th>
<th>Richter Magnitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minor</td>
<td>3 - 3.9</td>
</tr>
<tr>
<td>Light</td>
<td>4 - 4.9</td>
</tr>
<tr>
<td>Moderate</td>
<td>5 - 5.9</td>
</tr>
<tr>
<td>Strong</td>
<td>6 - 6.9</td>
</tr>
<tr>
<td>Major</td>
<td>7 - 7.9</td>
</tr>
<tr>
<td>Great</td>
<td>8 or more</td>
</tr>
</tbody>
</table>
Measuring Earthquake Magnitude and Intensity

Magnitude and Intensity

**Magnitude**

\[ M_L = \log \frac{A}{A'} \]

- \( M_L \) local magnitude
- \( A \) seismic wave amplitude recorded in \( \mu m \) on standard Wood-Anderson seismograph located at a epicentral distance of 100 km
- \( A' \) amplitude of the zero magnitude earthquake for the same distance (1 \( \mu m \))

NB: *in terms of energy, each whole number increase corresponds to an increase of about 31.6 times the amount of energy released!!!
Intensity

- The assessment of earthquake intensity on a descriptive scale depends on actual observations of earthquake effects. Observation on the performance of building structures, natural phenomena, and human perceptions are essential for evaluating the earthquake intensity.

- It depends on the epicentral distance, local soil conditions, geology and topography. In a typical case the largest intensity is observed near the epicentre.

- The intensity scale consists of a series of certain key responses such as awaking, movement of failure, damages or total destruction. One of the most famous intensity scale developed to evaluate the effects of Earthquake is the Modified Mercalli Intensity (MMI) Scale. It’s composed by 12 levels of intensity.

- It does not have a mathematical basis. It is an arbitrary ranking based on observed effects!!!!
# Measuring Earthquake Magnitude and Intensity

## Intensity

### Levels of an Earthquake

<table>
<thead>
<tr>
<th>Level</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Instrumental</td>
<td>Detected only by seismographs</td>
</tr>
<tr>
<td>II</td>
<td>Feeble</td>
<td>Noticed only by sensitive people</td>
</tr>
<tr>
<td>III</td>
<td>Slight</td>
<td>Resembling vibrations caused by heavy traffic</td>
</tr>
<tr>
<td>IV</td>
<td>Moderate</td>
<td>Felt by people walking; rocking of free standing objects</td>
</tr>
<tr>
<td>V</td>
<td>Rather Strong</td>
<td>Sleepers awakened and bells ring</td>
</tr>
<tr>
<td>VI</td>
<td>Strong</td>
<td>Trees sway, some damage from overturning and falling objects</td>
</tr>
<tr>
<td>VII</td>
<td>Very Strong</td>
<td>General alarm, cracking of walls</td>
</tr>
<tr>
<td>VIII</td>
<td>Destructive</td>
<td>Chimneys fall and there is some damage to buildings</td>
</tr>
<tr>
<td>IX</td>
<td>Ruinous</td>
<td>Ground begins to crack, houses begin to collapse and pipes reak</td>
</tr>
<tr>
<td>X</td>
<td>Disastrous</td>
<td>Ground badly cracked and many buildings are destroyed. There are some landslides</td>
</tr>
<tr>
<td>XI</td>
<td>Very Disastrous</td>
<td>Few buildings remain standing; bridges and railways destroyed; water, gas, electricity and telephones are out of action</td>
</tr>
<tr>
<td>XII</td>
<td>Catastrophic</td>
<td>Total destruction; shaking and distorsion of the ground</td>
</tr>
</tbody>
</table>
The major differences between Magnitude and Intensity are:

**Magnitude**
- Based on measuring the ground motion with instruments (seismographs)
- It’s a unique indicator of a size of an earthquake. Each earthquake is characterized with a single value which indicates its magnitude
- It’s a modern indicator. There are not measures of historical earthquakes.

**Intensity**
- Based on observations of earthquake effects on building structures and human perceptions
- It’s not a unique indicator of a size of an earthquake. Each earthquake is characterized with various intensities, depending on the location of a particular site with respect to the epicentre
- It can be evaluated also for historical earthquakes basing on the analysis of written source.
Historical Earthquake

Historical earthquakes

- Basel, CH, 1356
- Lisboa, PT, 1755
- Oslo, NO, 1904
- Amatrice, IT, 2016
• Most Earthquakes are usually rather short in duration, often lasting only a few seconds and seldom more than a minute or so.

• Although the intensity of the quake is measured in terms of energy released at the location of the ground fault, the critical effects on the given structures is determined by the ground movements at the location of the structure. The effect of these movements is affected mostly by the distance of the structure from the epicentre, but they are also influenced by the geological conditions directly beneath the structure.
Characteristics of earthquakes

Accelerogram

One of the most common representation is **acceleration** of the ground in one horizontal direction plotted as a function of elapsed time. How can we say if an accelerogram is hard for a structure?

[Graph showing acceleration vs. time]

Modenesi Tower, Italy

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How can we say if an accelerogram is hard for a structure?

- **Peak Ground Acceleration (PGA)**: The peak value in absolute value terms
- **Strong motion Duration**: Structural damage strongly depends on the number of load cycles
- **Fourier Spectrum**: It constitutes the representation of a time history into the frequency domain and it’s simply defined as the Fourier Transform of the ground motion time history. The description of the frequency composition is known as the analysis of its frequency content.
How can we say if an accelerogram is hard for a structure?

- **Acceleration Response Spectrum**: it is simply a plot of the peak acceleration value of a series of oscillators of varying natural frequency, that are forced into motion by the same ground motion. As we see it may be considered the main tool to evaluate seismic load.
Seismic risk is defined as the potential economic, social and environmental consequences of hazardous events that may occur in a specified period of time.

\[ R = H \cdot V \cdot E \]
Seismic Risk

**Hazard** Occurrence of an earthquake of sufficient magnitude capable of causing damage to the structures.

**Vulnerability** Damageability of the structures under action of the hazard; weaker ones being more vulnerable.

**Exposure** Assessment of economical and social consequences. It’s a count of the exposed system and their value.

How can we cut the seismic risk down?

- It is not possible to avoid or predict the occurrence of the earthquakes
- It is not possible to eliminate the presence of the man and the structures
- It is possible to limit the earthquake effect (Vulnerability) carrying out adequate RISK REDUCTION POLICIES
Conclusions

• Earthquake is an unpredictable natural phenomenon, results of a sudden release of energy.
• The nature of earthquakes can be explained by means of the plate tectonic theory.
• Magnitude and Intensity are the most widely accepted indicators for the size of an earthquake.
• The severity of an earthquake may be analyzed by some parameters (PGA, Duration, response Spectrum, ...)
• Earthquakes do not kill people, unsafe structures do!!!!