Lessons from the 1755 Lisbon Earthquake

Carlos Sousa Oliveira
Maio 2016

csoliv@civil.ist.utl.pt

European Federation of Geologists – Lisbon, Portugal
Summary

• Seismo-Tectonic environment
• Description of the earthquake
• First measures taken in the immediate
• Planning the future
• Final consideration
Book on “terramoto de 1755” (2009)
Book on “terramoto de 1755” (2009)
Azores-Gibraltar Fracture Zone
INHERITANCE (Legacy)
Seismicity in Europe 1980-2010 (IRIS, 2011)
Seismogenic Areas

Earthquakes occurred during the last Millennium

- Magnitudes [Richter]
  - 1 - 5
  - 5 - 7
  - 7 - 8
  - 8 ...

Lower Tagus Valley Fault

Gorringe Bank

(Cabral et al, 1996)
Seismicity in Portugal

Mapa de Sismicidade (IM)
1961-2007
Historical 1996-2013
Plant of Lisbon in 1650
View of the Square near the River
View of downtown Lisbon
1755: A MULTIPLE HAZARD EVENT

• First seismic waves in Lisbon - 9:40 h (8-10 min duration)

• Tsunami arrival in Lisbon - 11:00 h

• Fire – initiate same time and last for 6 days

Magnitude 8.8?-9.0;
Epic: 350 km SW Lisbon in Ocean
The 1755 Lisbon Earthquake & The March 11, 2011 Japan Earthquake

The importance of the 1755 Lisbon earthquake is known worldwide not only among the scientific and technical communities but also in many other disciplines of human kind related to the effects and consequences of the earthquake. Shaking, tsunami and fire caused great destruction. Reconstruction lasted for many decades and the earthquake brought in a set of new developments which definitely marked the downtown of Lisbon.

Comparisons with March 11, 2011 are very interesting and bring the importance of cultural legacy into nowadays.
Map of isosseismals (MSK Intensities) from the earthquake of November 1st 1755

Map of isosseismals (IMM Intensities) from the earthquake of 11/3/2011

Source: based on Martinez Solares et al. (1979); Levret (1991); Moreira (1984) and Mendes et al. (1999).
How the shaking was felt after descriptions of many witnesses

- a first shake with 1-2 min not very intense
- a pause of 1 min
- a second shake with 2-3 min (initiation of destruction) very intense
- a short pause of less than 1 min
- a third shake with 3-4 min, less intense and attenuating with time

Total between 6 to 8 min in Lisbon
Duration of vibrations as function of distance (composed after Martinez-Solares, 2000)
• Tipo de movimento do solo
  - logo imediatamente passou a terra rolando e tremendo espantaram-se de cousa nunca vista.
  - fazendo ao mesmo tempo a terra ondas como o mar.
  - o infausto terramoto levantando a terra com tal impulso que as telhas dos telhados e as paredes e se moviam como se soltassem
  - "..."estando eu no confessionário principiei a ouvir um tal estrondo que meteria medo ao homem mais destimido, logo vi que as sepulturas se levantavam do solo que parecia estarem a ressurgir os mortos, as lâmpadas de tal sorte se moviam que quase iam às paredes, e as mesmas paredes se levantavam e moviam de tal sorte que nem esperava a gente que elas ficassem em pé”.
• se levantava a terra para cima, e se deprimia por baixo com pequeno impulso
• -levantode-sea terra e baixando-se com um movimento direito
INFLUENCE ON RIVERS, SOURCES AND LAKES

• Alterações do nível de cursos de água e lagunas
• Houve fontes cuja água parecia leite
• O Rio Tejo no tempo do terremoto baixou 3 palmos e logo cresceu e saiu do seu ordinário quatro palmos e todo o tempo que durou estiveram as águas muito bravas fazendo grandes grutas.
• Secagem de fontes e aparecimento de outras
• Rios com maior ou menor caudal
• Ribeiros secos
• Agitação das águas
• Fenómenos compatíveis com liquefação/alterações no solo
• Tipo de informação validada:
• - pelo campo se abriram umas fendas na terra.
• - de tal sorte que muita gente que saiu da igreja a tempo, que a terra se agitava abrindo em fendas, temeu ficar subvertido
• - a terra abriu fendas notáveis especialmente junto dos rios
• - muitos campos rebentaram olhos de água e que em breve espaço secaram e que pelos mesmo saiu areia muito fina de cor preta, com cheiro a sulfúrico.
• - Em alguns vales se abriram alguns buracos por onde saiu água negra com grande força por modo de esguicho.
• - no campo se viram pular mais de 50 olhos de águas debaixo rebentavam e subiam 5 palmos, também abriram as terras de campo alguns furos.
• - abriu a terra grande fossa e imediatamente saía dela água com tanta violência que subiu a grande altura
• - baixou a terra mais dois palmos.
“Questionnaire send by order of the Marquis of Pombal, after the earthquake of 1755, to the different parishes of the country”

1° At what time did the earthquake started and how much did it last?
2° Did you notice a bigger impulse in one side than in the other? From north to south, or, in the contrary, did you notice that ruins felt more to one side than to the other?
3° Number of houses ruined in each parish; where there any special buildings and what is their state now?
4° What kind of people died? Were there any nobles?
5° Which novelties were seen in the sea, rivers or fountains?
6° Did the tide get low or high first; how much did it grown more than normal, how many times was the flow or unusual reflux noticed; how much time took the water to get lower and how much to get higher?
7° Were there any cleavages in the ground, what was seen there, and did any fountain came out again?
8° What were the measures taken locally by the priest, by the soldiers and by the ministers?
9° Were aftershocks felt? When? Which damages caused?
10° Do you remember any other earthquake and what damages did it cause?
11° What is the number of people in each parish, declaring when possible how many women and men?
12° Was there any kind of lack of food?
13° Where there any fire, for how long and what kind of damages caused?
extra Were you victim of any ruin from the earthquake of 1755, what king and is it already repaired?
Spatial component of linear predictor

Brillinger 2009
Attenuation Waves (GMPE)

\[ y = c_1 \exp(-c_2 R)M^{c_3} \]

Terramoto 1755

Nr. de observações: 821 (Portugal, Espanha)
Aplicação do modelo Levenberg Marquart
Área circular da falha com um raio de 90 km
Epicentro [30,01 N, 10,57W]
SRAPOR
João M. C. Estêvão
(2012)
Simulation of ground motion, by rupturing long fault

SIMULSIS
João M. C. Estêvão
(2012)

© 2012 CNES/Spot Image

Data SIO, NOAA, U.S. Navy, NGDC, GEBCO
Other simulations – University of Évora

Observed intensities

Simulated intensities

Gorringe Bank Rupture
Other simulations – LNEC

(Alexandra Carvalho et al, 2004)
Great destruction in the building stock and on Monumental Heritage

Opera House

Patriarcal
This 55 m high masonry arch-bridge structure made of well cut blocks that survived the earthquake with just minor damage on some local spots at the running deck. Ground motion should not overpass a PGA of 0.25g.
The ground motion produced had high energy content on the lower frequencies as it can be observed on the long period oscillations of suspended lamps in churches at long distances from the rupture area as Barcelona or on the oscillation in lakes in northern Europe (Seiches).
QUANTIFICATION OF DAMAGE
Tsunami and fire

Fire last for 5/6 days
Most of damage come from fire not from shaking or tsunami
Death toll

- Lisbon population (prior to EQ): 150,000 inhabitants
- Deaths: 5,000 – 8,000 (3.3%)
- From the total of 89 convents with 8,900 persons, 276 were killed (3.1%)
- Portugal (except Lisbon): 2,000 – 4,000
- Number of victims in Spain: 1,214 – 2,000
- Another 10,000 people were killed in Morocco

- Total deaths: 15,000 – 20,000 persons

Other sources estimates vary from 6,000 to 60,000 victims
Building damage

- Buildings: Poor masonry walls with timber floors, 4/5 and 6 storey high
- Buildings with larger sizes suffer most
- 10% destroyed
- 30% usable
- 60% unusable
Slopes

Geological Units (1:5M)

Main direction of movement

Tavares, 2016
Liquefaction and other geotechnical features

Building damage
Liquefaction in historical events

Jorge 1994
Tsunami Research

- Historical information
- Analytical modelling
  - At large
  - Over the coast
The 1755 tsunami was felt not only in the Portuguese coastal area of Lisbon (the harbor of Setubal was submerged by an enormous wave, in the Algarve, the waves reached great heights and in Ria de Aveiro 250 km north of Lisbon, the waters entered a few km inland destroying the agricultural productions) but also in the Southeast of Spain, in the North of Africa, in Great Britain and in The Netherlands, indicating the power associated (Oliveira, 2008).

The tsunami was also felt in the coast of America: in Antigua, 6,000 km away from Lisbon, the first wave of the tsunami arrived ten hours after the earthquake with records of about 3.5 meters height.
The tsunami impact

- Flooded many areas along the coast entering 2/3 km in the flat areas of South Coast (Algarve)

- Caused 30 m high waves in cliff areas

- Inside Lisbon Harbour it acted as a 3x15 min tidal wave, entering in many places but damped by the existence of City walls and a profuse narrow street fabric

- The lack of knowledge made people run to lower plaza near the river after the shaking, causing high mortality when tsunami arrived and also during rundown

- In northern area of country (500 km from epic) the tsunami went over the sandy cost line and destroyed cultures in a lagoon (Ria Aveiro)
Various simulations indicate that an earthquake like 1755, with epicenter 150 km SW Portugal would produce waves 12m heigh in the Algarve within 17 min.
Azores Islands 2h40m
1755 Lisbon Tsunami – time and height

Wikipédia, 2012
Comparison with the Tsunami 11/3/2011

Travel time: 1 hour contours interval

Height of water
TSUNAMI EFFECT IN THE COASTAL AREAS
The tsunami was felt not only in the Portuguese Coast, but also in the Southeast Spain, North of Africa, Great Britain and The Netherlands. Hours later in the eastern coast of the Americas

Tsunami source – Elastic Half space approach, using Mansinha & Smiley1971 or Okada’s equations 1985
Data for tsunami source model: Rupture Dimensions, dip angle, rake, azimuth, slip
Santos et al. 2013
<table>
<thead>
<tr>
<th>Place</th>
<th>Travel time (min)</th>
<th>Initial response</th>
<th>Run-up (m)</th>
<th>No. waves</th>
<th>Period</th>
<th>Duration of perturbation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-Opo.</td>
<td>---</td>
<td>Uplift</td>
<td>&gt; 1.2 – 1.5</td>
<td>---</td>
<td>15 min</td>
<td>More than 4h</td>
</tr>
<tr>
<td>2-Mir.</td>
<td>80</td>
<td>Uplift</td>
<td>---</td>
<td>Several</td>
<td>30 min</td>
<td>1h 30 m</td>
</tr>
<tr>
<td>3-Fig.</td>
<td>---</td>
<td>Uplift</td>
<td>36</td>
<td>3</td>
<td>2 hours</td>
<td>Till sunset</td>
</tr>
<tr>
<td>4-Lav.</td>
<td>38 – 45 (1)</td>
<td>Uplift (1)</td>
<td>---</td>
<td>1</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>5-Vie.</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>1</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>6-Por.</td>
<td>75 (1)</td>
<td>Uplift (1)</td>
<td>16.2 – 18 (2)</td>
<td>3</td>
<td>---</td>
<td>All afternoon</td>
</tr>
<tr>
<td>7-Eri.</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>All day</td>
<td>---</td>
</tr>
<tr>
<td>8-Cas</td>
<td>---</td>
<td>Uplift</td>
<td>12</td>
<td>3</td>
<td>brief time</td>
<td>---</td>
</tr>
<tr>
<td>9-Cru.</td>
<td>23 – 30 (1)</td>
<td>Uplift (1)</td>
<td>6</td>
<td>3</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>10-Bug.</td>
<td>30 (1)</td>
<td>Uplift (1)</td>
<td>---</td>
<td>3</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>11-Set.</td>
<td>---</td>
<td>---</td>
<td>6 – 17.5</td>
<td>3</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>12-Arr.</td>
<td>---</td>
<td>Subsidence</td>
<td>-54</td>
<td>3</td>
<td>---</td>
<td>Few minutes</td>
</tr>
<tr>
<td>13-SVC</td>
<td>6 – 7 (1)</td>
<td>Subsidence (1)</td>
<td>N: -11; E: -14</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td></td>
<td>16-17 (1)</td>
<td>Uplift (1)</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>14-Bel.</td>
<td>---</td>
<td>Subsidence</td>
<td>54 (2)</td>
<td>3</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>15-Sag.</td>
<td>---</td>
<td>Uplift</td>
<td>N: 108; E: 144 (2)</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>16-Mar.</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>3</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>17-Boc.</td>
<td>---</td>
<td>Uplift</td>
<td>10 – 12</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>18-Lag.</td>
<td>23 – 30 (1)</td>
<td>Uplift (1)</td>
<td>6 – 9</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>19-Por.</td>
<td>---</td>
<td>Uplift</td>
<td>10.8</td>
<td>---</td>
<td>Few minutes</td>
<td>Till 4 PM</td>
</tr>
<tr>
<td>20-Alb.</td>
<td>---</td>
<td>Uplift</td>
<td>10.5</td>
<td>3</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>21-Quar.</td>
<td>---</td>
<td>Uplift</td>
<td>10.8</td>
<td>5</td>
<td>---</td>
<td>---</td>
</tr>
</tbody>
</table>

Table 1 – Summary of tsunami parameters. (1) Data compiled from Santos et al., 2009; (2) At the cliffs
Setúbal wave motion
FIRST MEASURES AND PLANNING THE FUTURE
King Joseph I

Marquês de Pombal (Acting Prime Minister)

- Great political and executive power
- Very controversial person due to his form of ruling

Technical/Management team (Military Engineering)

- Manuel da Maia (Chief Engineer of the Kingdom)
- Eugénio dos Santos (Capitão de Engenheiros e Arquitecto do Senado)
- Carlos Mardel (Hungarian – Ten. Coronel Engenheiro e Arquitecto)

Sala do Risco das Obras Públicas (Design Office for Public Works)
DISASTER MANAGEMENT

• Prior to the Earthquake.
  There were no signs to call the attention of the population, even though several indications can be suggested as pre-events, such as the time delay of full tide, the presence of sand boils, etc.

• During the Earthquake.
  Population had no indication whatsoever of how to deal with earthquakes. The presence of a strong tsunami has never been reported and all the information classifies these natural extreme events as acts of God to punish bad behavior of the population.
Post-Event (measures to reduce the impact)
Several measures were implemented in the first 24 hours past the earthquake in order to keep the situation under control. Out of 233 measures until June 1758, 24 were announced in the first 72 hours, 47 during the first week and 100 in the first month (Mineiro, 2005).
These measures contemplate the most important acts to:

- Avoid spreading of epidemics (plague), housing and feeding the population, and guarantee the safety of the people because prisons collapsed and a large number of in prisoners escape and were trying to assault the rich houses, protect the City from assaults by pirates, save the gold reserves, etc.
- The ones who did not comply with the authorities were decapitated. There were several locations for those acts which gather a lot of attention from the population.¹

¹We should remind that Portugal was one of the first countries eradicating the death penalty which was abolished for political crimes in 1852.
These measures contemplate the most important acts to (cont):

- Take care of the wounded was one of the first decisions as well as to bury the dead. Most of these were mixed with the ruble of the collapsed buildings, others were sent to the sea in special boats and without religious ceremonies.
- Launching of an inventory to the priests of all parishes around the country to understand the damage inflicted by the earthquake was of great importance to evaluate the impact on the population and on the economy.
THE RECONSTRUCTION OF LISBON

Five alternatives for reconstruction

• Rebuilt the City as it was before the earthquake
• Rebuilt the City as it was before, keeping the same height but taking the opportunity to suppress narrow streets, making them wider
• The same as before but limiting the height of buildings to only 2 stories above ground floor
• Demolish all the downtown replacing it with a new urban plan with wide streets with freedom to built in height as well as in plan
• Leave the destroyed City and build a new City to the west in a region where the shaking has been less intense. (Belém, de Alcântara a Pedrouços)
INNOVATIONS

• “Gaiola” (Wooden cage): earthquake resistant construction
• “Corta-fogo” (Firewall): fire resistant partitions were incorporated into the buildings
• Foundations: pine piles to strengthen the rubble mat
• The Size: ground floor plus 2 storey and an attic
• Design and urban regulations: reconstruction plan incorporated some urban planning elements (regular block dimensions for easier access-ingress, recommended street width and distance between buildings)
• New technologies were implemented such as sanitary ducts and sanitary vaults in the middle of the roads.
New urban plan
A Block of Buildings (Baixa Pombalina)
The first Worldwide Earthquake-Resistant Code of Practice

• Due to building provisions introduced after the 1755 EQ, it is believed that Lisbon was the 1st city in the world to have a code for seismic-resistant construction.

• This code, prepared after the earthquake defined the basic principles for reconstruction of the city.

• One of the innovations introduced in this code was the concept of wood-braced frames (“gaiola”) interacting with and supporting the masonry elements. This concept soon was adopted in other countries.

• The code limited to 3 the number of stories permitted in new construction.
Façade in the blocks
Façades

Plan geometry
Cross-section
Extruded view

Pile foundation and ground floor vault
Water sanitation seen across the block and sewage
Tabique

Lab test with applied horizontal load
Today’s view of downtown Lisbon
Proposta de Mapa de Perigosidade EC8
Algarve Seismic Simulator

SEISMIC SIMULATORS

ERSTA, ANPC, 2009
Casos de Estudo – AML + ERSTA (ANPC)
Estudo do Risco Sísmico das Área Metropolitana de Lisboa (AML) e Algarve (ERSTA)
M9.3 earthquake scenario, Marquês de Pombal Fault (Intensities IMM)
M8.5 earthquake scenario, Marquês de Pombal Fault
(Deaths per block)
SEISMIC SIMULATORS

M8.5 earthquake scenario - Marquês de Pombal Fault
(Energy network)

ERSTA, ANPC, 2009
Tsunami impact

Scenario 1755

IMM máxima |

27 779 (0,28%) mortos

26 253 edifícios colapsados

6,1% área perdida

0,88% edifícios colapsados
Reinforcement of Pombaline buildings?

The present situation of the Pombaline buildings is of great concern because of the degradation of the general structural system due to aging, change of functionality, replacement of transverse walls by steel beams, bad foundation conditions, etc.

There has been a number of solutions to cope with this degradation, but unfortunately the authorities were not very receptive to the earthquake reinforcing, preferring to work only with the maintenance of the situation. There is no code for earthquake reinforcement besides what EC8 part 5 recommends.

The solutions can be classified into two large groups: the first advocates the use of measures with large interventions at the level of introducing RC elements or metallic elements, wire meshes in the walls, etc. The second group advocates a minimal intervention with the use of connectors for better linkage among walls, reinforcement of foundations, use of pos-tension cables, etc.

This problem is of great importance to keep downtown Lisbon a place of cultural heritage more earthquake safe.
Modeling and retrofit

Lourenço et al, 2008

Coias e Silva, 2005
ECONOMICAL LOSSES
1755
## Total Direct Losses (from Santos Pereira 2007)

### Table 4 _Losses from the Earthquake, Fire and Tsunami (in contos)_

<table>
<thead>
<tr>
<th></th>
<th>Quantity</th>
<th>Estimated damage per unit (million reis)</th>
<th>Total by Historical Accounts (Estorninho 1956)</th>
<th>Total by historical accounts II (Pereira 1953)</th>
<th>Total by historical accounts I (França 1983)</th>
<th>Total New estimates (million reis)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dwellings</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Burned parish</td>
<td>11,639</td>
<td>0.980</td>
<td>11,173</td>
<td>11,173</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ruined parish</td>
<td>3,865</td>
<td>0.950</td>
<td>3,71</td>
<td>3,71</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Damaged</td>
<td>~5,000</td>
<td>0.1-0.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Convents monks</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Burned + ruined</td>
<td>8</td>
<td>120</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Only Ruined</td>
<td>22</td>
<td>80</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Less ruined</td>
<td>9</td>
<td>20</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Convents nuns</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ruined</td>
<td>24</td>
<td>80</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Less ruined</td>
<td>2</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Recolhimentos</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Burned</td>
<td>3</td>
<td>60</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ruined</td>
<td>3</td>
<td>40</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Less ruined</td>
<td>1</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Churches destroyed</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Burned parish</td>
<td>17</td>
<td>80</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other parish</td>
<td>16</td>
<td>80</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Damaged</td>
<td>59</td>
<td>20</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Interiors of Churches</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hospitals</td>
<td>6</td>
<td>100</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Palaces</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ruined + burned</td>
<td>28</td>
<td>300</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Terreiro do Paço</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diamonds</td>
<td>12,800</td>
<td>4,000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Gold, Silver, Furniture</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crown</td>
<td>4,802</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Private</td>
<td>8,003</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Church</td>
<td>5,122</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Money Lost</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Losses by foreigners</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Outside Lisbon</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dwellings^9</td>
<td>5-7,000</td>
<td>0.640</td>
<td>n.a.</td>
<td>n.a.</td>
<td>n.a.</td>
<td>3,200-4,480</td>
</tr>
<tr>
<td>Convents</td>
<td>5-10</td>
<td>50</td>
<td>n.a.</td>
<td>n.a.</td>
<td>n.a.</td>
<td>250-500</td>
</tr>
<tr>
<td><strong>Grand total</strong></td>
<td></td>
<td></td>
<td>85,600</td>
<td>266,240</td>
<td>229,520</td>
<td>63,693-72,193</td>
</tr>
</tbody>
</table>

### Notes
- Sources: Pereira de Sousa (1931), Matos and Portugal (1967), Conceição (1870), Pereira (1983)
- Damage as % of GDP
- Total New estimates (million reis): 11,173, 3,71, 500-1,000, 960, 1,760, 180, 1,920, 20, 180, 120, 10, 1,350, 1,280, 1,180, 600, 11,200, 4,000, 4,000, 1,000-2,000, 10-15,000, 1,000-2,000, 12,800.
contemporary accounts with trade data for 1755 to get an estimate of around between 100 and 150,000 contos. Since the estimates for Portuguese GDP in the early 1750s are between 150,000 contos (Valério 2002) and 150-200,000 contos (Cardoso 2005a), the total direct GDP losses vary between 43%-57% (Estorninho 1956), 75%-100% (Cardoso 2005a), 115-153% (França 1983) and 133-178% (Pereira 1953) of Portuguese GDP.

Santos Pereira, 2007
Probability of repetition of a similar event

- Large events with low probability of occurrence
- Erroneous way of playing with Return Periods (problems with recent events: Kobe; Athens; Haiti; Tohoku; etc.)
- The present situation is very difficult for assets like these cultural legacy, for the effect of tsunami in all coast

- Repetition of a event similar to 1755 today we would have ten’s thousand of victims and 1 to 2 x GDP losses
Obrigado - Thank you