ON THE NECESSITY TO ESTABLISH LOCAL SEISMIC HAZARD MAPS FOR URBAN REGIONS

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ABSTRACT

In order to manage urban developments, it is necessary to define the design basis accurately. In urban regions with high earthquake risk, local seismic hazard maps are necessary to properly plan new developments and to ensure that upgrading of existing buildings and infrastructure be carried out properly. The local hazard maps will take into account the following information:

- Effects of local faults
- Effects of local soils conditions, including the thickness of the soils layers

The main usages of this information are:

- Definition of design basis for new buildings
- Definition of necessary earthquake strengthening of existing buildings
- Identification of necessary emergency measures like firewater and access by fire equipment and ambulances
- Definition of locations of safe shutdown valves for gas
- Identification of muster points for local population to avoid hazards caused by jet fires etc.

A case study is presented where particulars of a mayor mega city (Tehran) and a smaller densely populated city (Oslo) are compared. The requirements of both cities are spelled out and suggestions for use of the local seismic hazard maps are presented.

INTRODUCTION

Damages due to earthquakes can be huge and it is of most importance that all efforts are made to reduce the consequences of earthquakes. It is 20 years since the Kobe earthquake (M = 7.3 on 17th January 1995) and the city infrastructure was not designed for such a quake, although numerous quakes larger than this magnitude have struck Japan. Consequence reduction efforts have to be implemented where the risk is highest, i.e. where the probabilities are highest and the consequences of damages are largest and where the effects on spending funds are given the most benefits.

Mapping of the most vulnerable areas represents a good guideline to where one should implement risk reducing measures. For urban areas this is achieved through preparation of seismic zonation maps. The most vulnerable areas are normally the areas close to known faults and for buildings and infrastructure on softer soils. Damages during historical earthquakes shall also be taken into account and specific resonance frequencies should be identified. Reference is made to the Mexico City earthquake of 19th September 1985 (M = 8.1) where the lakebed has an Eigen period of around 2.5s; in resonance with mid height buildings.

Older and not so tall colonial buildings have survived many quakes as they are not in resonance with the natural period of soil amplification. We will refer to the cities of Oslo, a mid-size city in an intraplate area and Tehran, a megacity in a high risk earthquake zone and discuss the seismic hazard maps and their important applications.

CASE STUDY: OSLO, NORWAY

The earthquake risk in Oslo, the capital of Norway is generally considered to be low. The seismic zonation map of Norway, however, shows that the Oslo Fjord area (Figure 1) has amongst the highest peak ground acceleration values due to its closeness to the Oslo Fjord fault that follows the eastern shores of the Oslo Fjord (Bungum et al., 2009).

A major earthquake struck the Oslo Fjord on 23rd October 1904 with an M_s of 5.4 (Figure 2). The earthquake was strongly felt in parts of Oslo, in particular in buildings situated on softer sediments and in communities south of Oslo; brick walls cracked and chimneys fell down. Panic occurred in some churches in the center of the city as the earthquake occurred during the Sunday mass and the congregations fled to the doors (Falck, 2011). Some buildings were demolished after the earthquake.

On the southeastern shores of the fjord, the Id medieval church (built before 1360) was struck and partly damaged; there were significant cracks in its old stone walls. The church is located on clay grounds amplifying the earthquake. The church was, however, repaired and the ground was stabilized. The church is still in use (Figure 3).

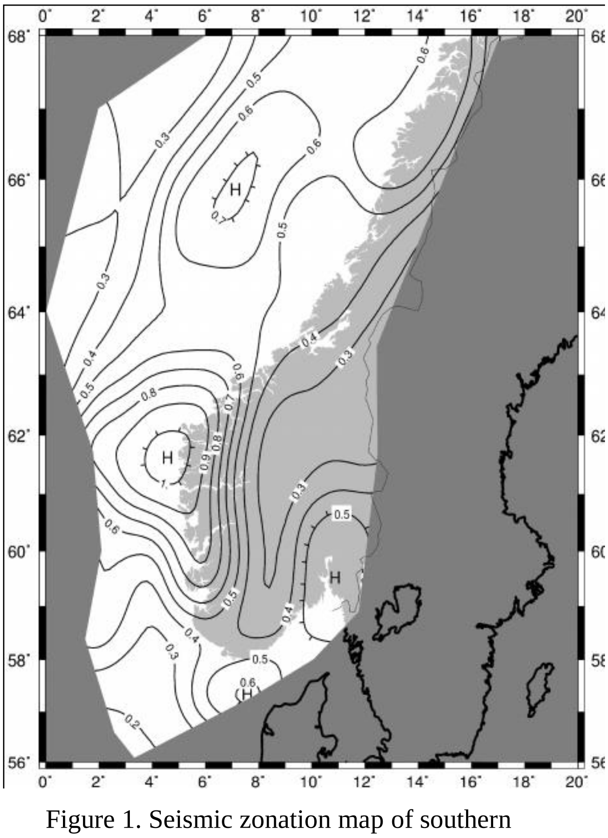

Figure 1. Seismic zonation map of southern Norway; recurrence rate of 475 years (Courtesy Norsar, Kjeller, Norway)

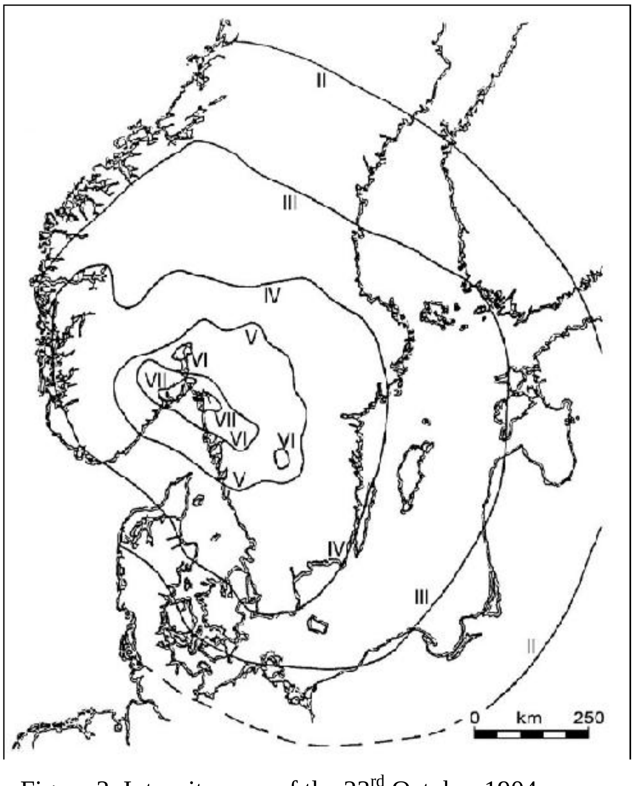

Figure 2. Intensity map of the 23rd October 1904 Oslo Fjord earthquake (Bungum et al., 2009, originally from Muir Wood and Woo, 1987)

Figure 3. Recent picture of the Id medieval stone church damaged during the 1904 earthquake and restored

Lindholm et al. (2007) studied the effect on the city of Oslo of a maximum credible earthquake (M=6.5) on the Oslo Fjord fault. They divided the city in 84 regions and estimated the damage for all regions. They included knowledge about soil conditions (Molina and Lindholm, 2003 and 2005) and categorized the damage in terms of moderate and complete, giving the most probable values assessments and the 16% and 84% fractals, see Fig. 4. It should be seen that the damage assessment varies considerable for the different regions of the city. The potential damage is largest in the old City Center, Sentrum, and to the east and north of Sentrum, the regions where the 1904 earthquake was felt strongest.

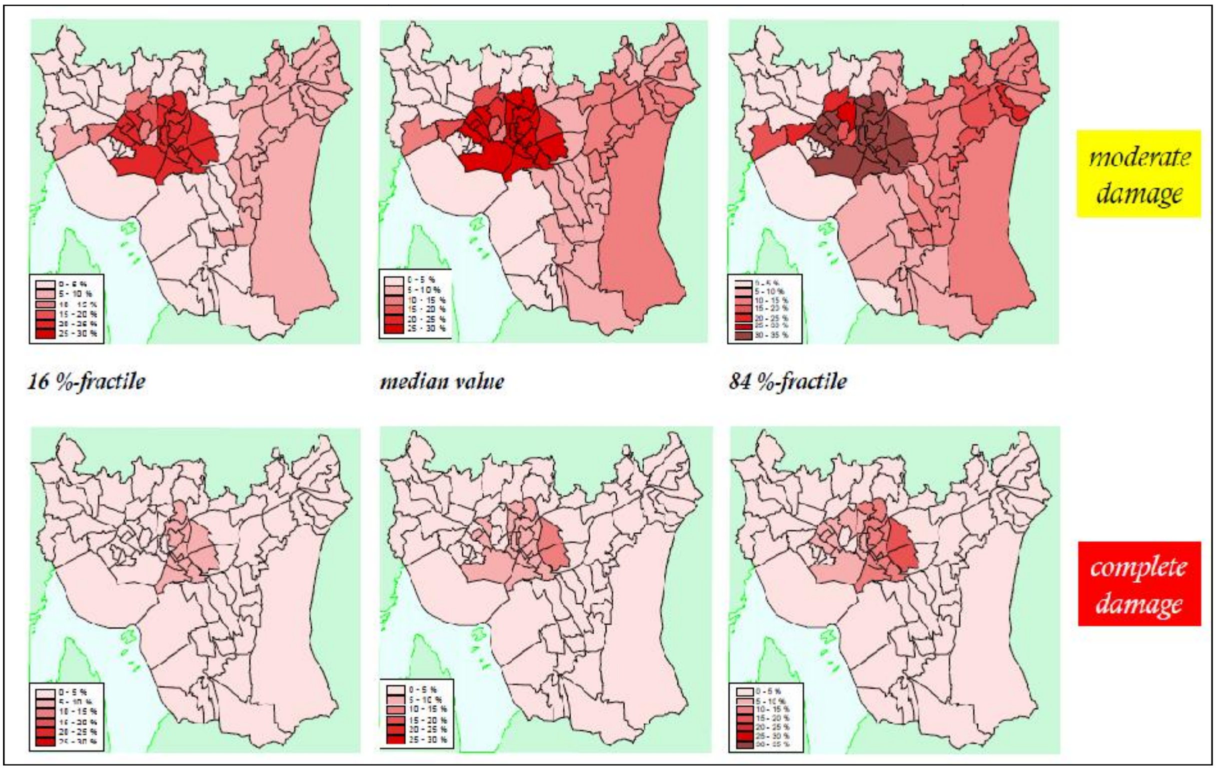

Figure 4. Damage scenario for downtown Oslo, Norway, when subjected to a M = 6.5 earthquake on the Oslofjorden fault. The figure shows the accumulated damage over all building classes for moderate and complete damage limit states. (Lindholm et al., 2007)

The recent development of the city of Oslo in Norway (640.000 inhabitants) is characterized by major construction of high rise buildings in the waterfront area where piling down to rock is necessary due to construction on landfills.

So, is there any concern regarding the earthquake hazard in Oslo? A recent study at NTNU, Trondheim (Harnæs Hoel and Svendsen, 2012) under the supervision of professors Rönnquist and Sigbörnsson has revealed that the tallest building in the city (located in the Sentrum) should be safe under a Friuli 1976 type (Ms = 6.5) earthquake. The Norwegian society of consulting engineers (RIF) has, however, in 2009 (VG, 2009) warned that the Parliament and the Royal Castle (also located in the City center) could see severe damage during moderate earthquakes as these buildings are masonry buildings located on soft soils.

Of high concern could also be schools and kindergartens in the eastern part of the City Center (see Figure 4). Renovation work of older masonry buildings should take into account the effects of damage during more probable earthquake situations where debris could fall from ceilings and walls. Possibly, children exercises could be carried out for those occupying potentially vulnerable buildings: “We hide under the table”. The seismic hazard map given in Figure 4 or possible clearer updates will be very useful to assess where potential concern could be raised.

CASE STUDY: TEHRAN

There is more than 150 year since the last major earthquake damaging Tehran. According to the catalogue of past earthquakes (Ambraseys and Melville, 1982), however, many earthquakes have in the past affected the city. This is reflected in the seismic hazard map of Iran, Figure 5. The largest historical earthquake affecting Tehran occurred in 958, having magnitude of 7/7 Mw, having epicenter 50 km away from the city center. This earthquake was probably related to activity on the western part of the Mosha fault. The North Tehran fault is located between the western part of Mosha fault and Tehran city (Figures 6 and 7). One is concerned that in case of a similar earthquake on the Tehran fault, large damages may occur, even larger than in the case of a situation similar to the earthquake in 958 (Hashemi et al., 2014).

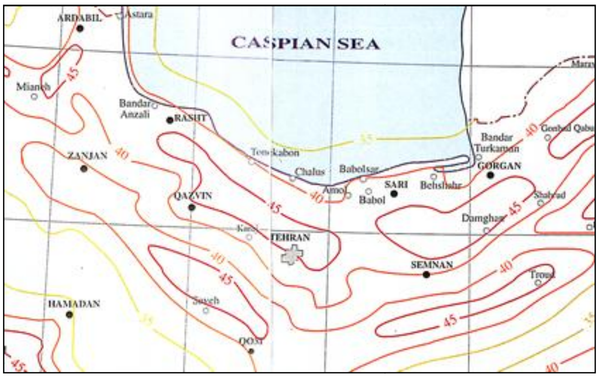

Fig. 5. Clip of iso acceleration contour map lines of Iran for a return period of 475 years. Prepared by Ministry of Culture and Higher Education, Islamic Republic of Iran

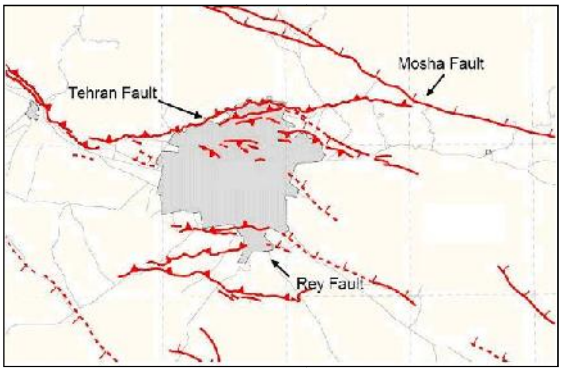

Fig. 6. Active faults around Tehran - courtesy of IIEES

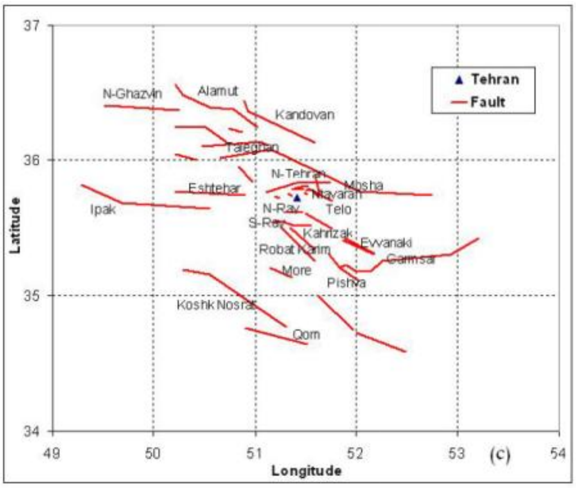

Fig. 7. Active faults of Tehran and its vicinity (Berberian et al., 1983)

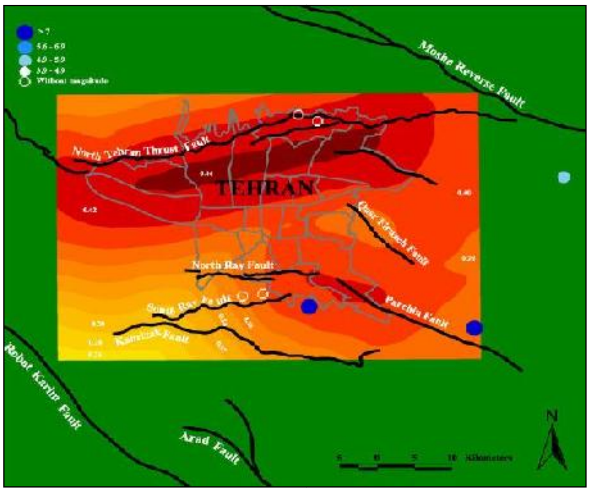

Fig. 8. Tehran seismic hazard map (10% probability in 50 years) - courtesy of IIEES

The vulnerability of the different regions of the city varies; see Figure 8, where the peak ground acceleration values are estimated (IIEES). Reference is made to Ghodrati Amiri et al. (2003). The higher values of the Northern Tehran shall be noticed.

Since the Arias intensity parameter includes all characteristics of ground motion, it represents, however, a clearer quantitative estimate of the ground motion. The Arias intensity measure ("accelerogram energy") is the sum of the energy absorbed by a population of simple oscillators evenly spaced in frequency (Kayen and Mitchell, 1997). Analysis of the Arias intensity has shown very large hot spots in north Tehran and south of Tehran Ghodrati Amiri et al. (2010), see Figure 9.

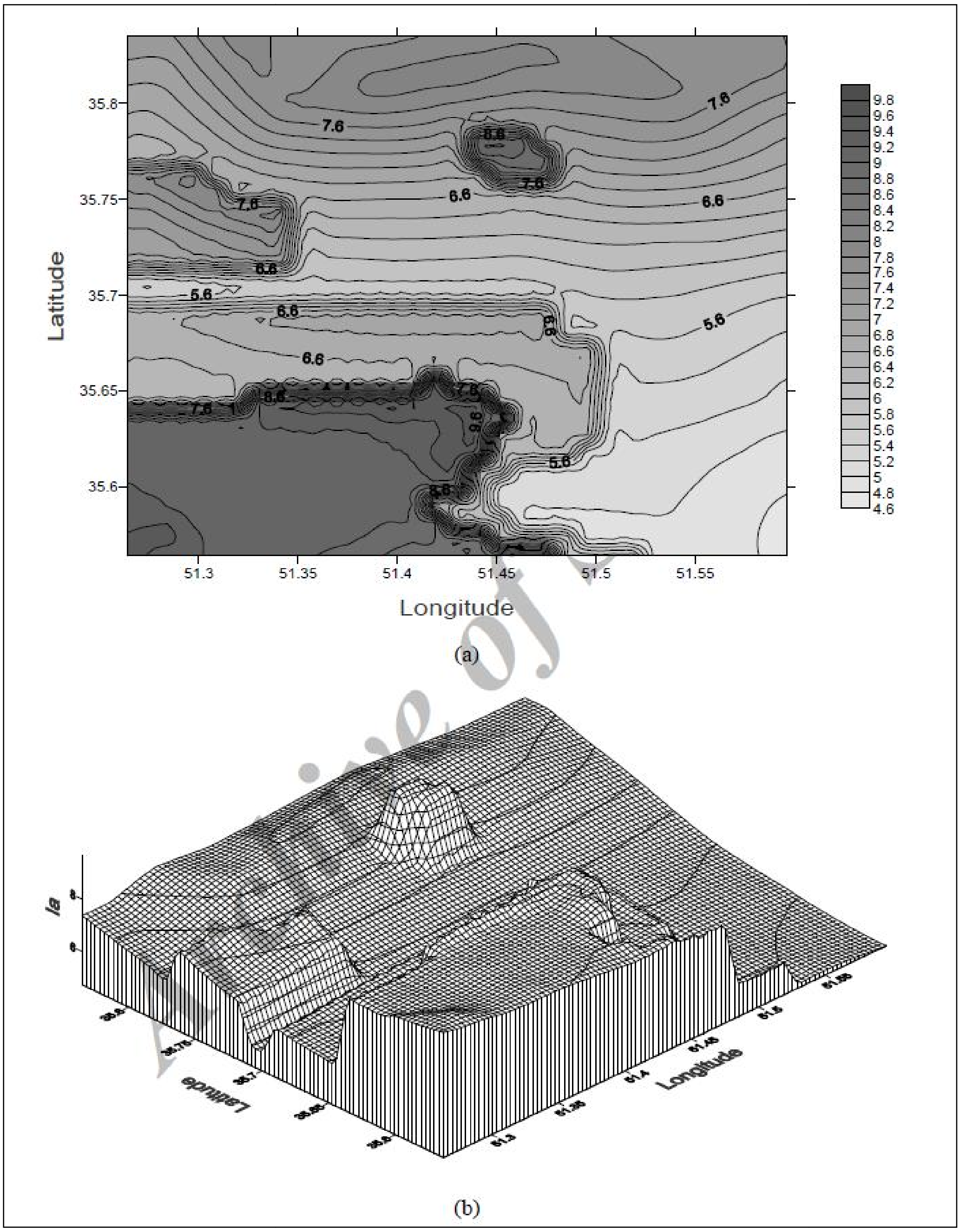

Figure 9. Seismic hazard maps in terms of arias intensity in Tehran and its vicinity using logic tree for 475 years return period (a) two-dimensional zoning map showing arias intensity (b) three-dimensional zoning map showing arias intensity (Copied from Ghodrati Amiri et al., 2010).

The information given by these seismic intensity maps is suggested to be very important for strategically planning of implementation of earthquake mitigation measures for the city. Of concern are among others:

- Definition of design basis for new buildings
- Definition of necessary earthquake strengthening of existing buildings
- Identification of necessary emergency measures like availability of firewater and access by fire equipment and ambulances
- Definition of locations of safe shutdown valves for gas
- Identification of muster points for local population to avoid hazards caused by jet fires etc.
- Identification of availability of fresh water supply after an earthquake has struck.

DISCUSSION

Even though the city of Oslo, Norway, is located in an intraplate region with relatively low seismic activity, past earthquakes have been observed (Bungum et al., 2009). The earthquake of 1904 caused some damages and a similar earthquake could potentially cause damages to the new structures being built. Deep clay deposits contribute to amplification of the earthquake signals and a seismic zonation map (Molinas and Lindholm, 2005) identify vulnerable areas and is considered very useful when planning rehabilitation works and new developments.

The mega city of Teheran (8.5 Million inhabitants) is very vulnerable to seismicity and seismic zonation maps are used extensively for planning purposes. Closeness to faults and underlying soil conditions represent the main parameters when identifying the seismic hazard.

CONCLUSIONS

For cities exposed to seismic hazard, seismic hazard maps should be developed for planning and re-development purposes. It is of most importance that main risks associated with seismic events are being mitigated whenever possible and at the most economically beneficial way. Seismic hazard maps identify the most vulnerable regions of the cities and are considered to be very valuable tools in urban development planning, not only for cities in high seismic risk areas but also for cities where the seismic risk is moderate.

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