Urban seismology – Contribution of building testings for assessing the seismic response and the seismic vulnerability of actual buildings

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ABSTRACT: Recent devastating earthquakes and induced seismicity near to cities have shown that urban areas must become the centrepiece of analysis in order to reduce seismic risk, facing up to global urban population growth and the concentration of wealth and modern infrastructure within cities. The last major earthquakes that caused considerable damage and losses have reminded politicians and decision makers that reducing seismic risk is essential, both for the well-being and safety of the local population but also for maintaining the global financial and economic balance. According to best practice in recent decades, the evaluation of seismic hazard is based on the compilation of all geological, tectonic and seismological data available in a region. Once analysed and interpreted, these data define the rate of occurrence of seismic events and the associated seismic ground motion. In general, seismic hazard assessment is evaluated at the country level and is represented in the form of seismic hazard maps. Once validated, seismic hazard is then translated into regulatory documents for the purpose of earthquake engineering and design. Efforts required to define hazard maps are usually uniformly distributed across a region: the most exposed areas, urban environments, are therefore not attributed more time and resources to define the seismic hazard at smaller scales. Focussing on urban areas for the prediction of seismic ground motion caused by natural or induced seismicity and the prediction of the response and protection of civil structures and infrastructure are therefore two critical topics in reduction of seismic risk for the increasingly urbanised global population.

The background (tectonic) hazard - or the number of *potentially* damaging earthquakes per year - has neither increased nor decreased in recent decades, only the vulnerability and exposure of communities have changed. According to the World Health Organisation, the urban population in 2014 accounted for 54% of the total global population, up from 34% in 1960, and continues to grow by approximately 1.5-1.6 % per year between 2015 and 2030. As a result, casualties due to earthquakes are expected to reach about 2.8 million by 2100[1]. In fact, because of the long return periods of the largest high-consequence earthquakes, and because few urban areas in their current configuration have yet to suffer such major events, Jackson[2] notes that the greatest earthquake disasters are yet to come.

Contrary to the case of tectonic events, in case of induced seismicity caused for instance by reservoirs, the withdrawal of trapped fluids and gases and the injection of fluids into the ground, the seismicity rate changes in time and space, with a sharp increase in seismicity, as in central Oklahoma, US[3]. Recently, the increased occurrence of induced earthquakes and their impact on the built environment have heightened both public concern and regulatory scrutiny. In Europe, where potential extraction sites are typically closely located to, or even within urban areas, this issue is more critical and must be

[1] Holzer & Savage," Global Earthquake Fatalities and Population", Earthquake Spectra, 29(1):155-175, 2013
[2] Jackson, "Fatal attraction : living with earthquakes, the growth of villages into megacities, and earthquake vulnerability in the modern world", Philosophical Transactions of the Royal Society, 364(1845):1911-1925, 2006.
[3] Keranen et al., "Sharp increase in central Oklahoma seismicity since 2008 induced by massive wastewater injection", *Science*, *345*(6195), 448-45, 2014.

addressed in order to provide robust guidelines to industry, regulators and society at large. While efforts must be developed to enable control of induced seismicity, rational solution must be proposed and based on risk quantification and mitigation measures in exposed urban area[4].

As consequences, seismic building response and potential damage prediction become a key-issue in order to provide relevant information for risk analysis and planning retrofitting program to reduce the seismic risk an. Usually, seismic risk is expressed as the convolution of seismic hazard and seismic vulnerability, considering their time invariance and the lack of data required for characterising hazard and vulnerability at scales suitable for integrating the space variability of the urban environment. However, risk probability may change in time, for instance as a consequence of induced seismicity sequences or aftershock sequences, coupled with the degradation of buildings. Furthermore, the lack of information may influence the accuracy of the risk assessment. In case of active policy for risk mitigation, the impact of decisions based on time variability and completeness of information might have a critical effect for decision-making, influencing the investment devoted to seismic risk mitigation and based on cost/benefit analysis.

When we want to reduce risk, vulnerability assessment of existing buildings is required. While the seismic design of new buildings is well-practiced thanks to the earthquake engineering and the seismic regulation, the assessment of existing buildings is complex because the information necessary for their evaluation are rare and difficult to collect. This is even more critical when we are concerned by a city or region exposed to natural or induced seismicity, the unfavourable balance between available financial resources and number of buildings to be assessed limiting the initiatives. This lack of information results in an increase of epistemic uncertainty of building fragility curves that we should be able to reduce if we want to improve our assessment and provide reliable information to policy makers and real estate managers facing earthquakes.

As for the prediction of the ground motion, the use of abundant and new data available at urban scale provides relevant and efficient information for characterising actual buildings and finally reducing epistemic uncertainties of their fragility. This presentation will be focused on this topic through experiences and methodologies developed and tested in Europe. Data can be provided by national census or remote sensing and the key issue remains in exploring the large amount of available information for extracting relevant characteristics used for vulnerability assessment. In addition, physical parameters of buildings provide also relevant information for vulnerability assessment and experimental testing in buildings are able to give relevant information on the building models, efficient for reducing epistemic uncertainties in their seismic response as well as on the damage prediction.

Bommer J.J., Xrowley H., Pinho. "A risk-mitigation approach to the management of induced seismicity", *Journal of seismology*, 2015. 10.1007/s10950-015-9478-z