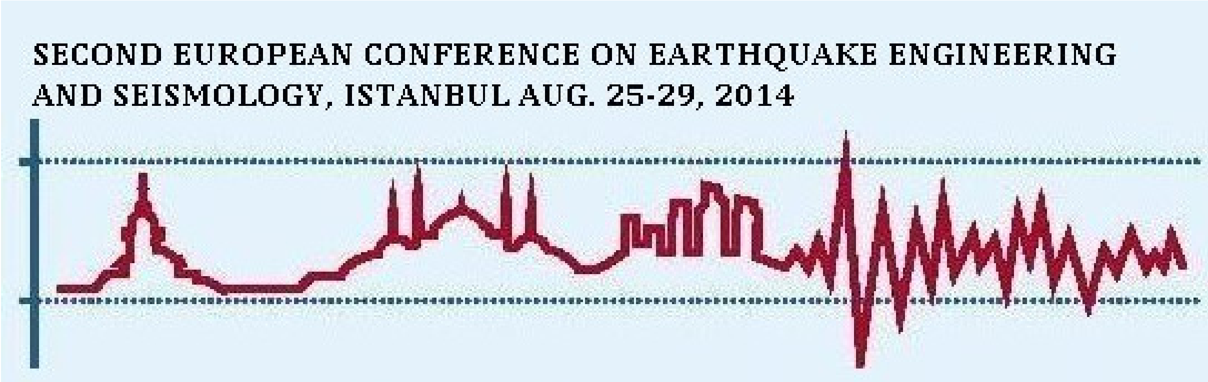

FRAGILITY FUNCTIONS FOR PHYSICAL ELEMENTS DUE TO SEISMIC RISK

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INTRODUCTION

Fragility curves constitute one of the key elements of seismic risk assessment. They relate the seismic intensity to the probability of reaching or exceeding a level of damage (e.g. minor, moderate, extensive, collapse) for the elements at risk. The level of shaking can be quantified using different earthquake intensity parameters, including peak ground acceleration/velocity/displacement, spectral acceleration, spectral velocity or spectral displacement. They are often described by a lognormal probability distribution function, although it is noted that this distribution may not always be the best fit. In the framework of SYNER-G project a comprehensive review has been carried out of fragility curves for most important elements at risk. Moreover, new fragility curves have been developed where necessary, considering the distinctive features of European elements (Pitilakis et al. 2014). The elements at risk are classified in four main categories: buildings, utility networks, transportation infra-structures and critical facilities. The key assumption in the vulnerability assessment is that structures and components, having similar structural characteristics, and being in similar geotechnical conditions, (e.g. a bridge of a given typology), are expected to perform in the same way for a given seismic excitation. Taxonomy and typology are thus fundamental descriptors of a system that are derived from the inventory of each element and system. Geometry, material properties, morphological features, age, seismic design level, anchorage of the equipment, soil conditions, and foundation details are among usual typology descriptors/parameters. In SYNER-G a comprehensive taxonomy was created, and typologies for the most important elements at risk in Europe were defined (Hancilar and Taucer, 2013).

DAMAGE STATES

In seismic risk assessment, the performance levels of a structure, for example a RC building belonging in a specific class, can be defined through damage thresholds called *limit states*. A limit state defines the boundary between two different damage conditions often referred to as damage states. Different damage criteria have been proposed depending on the typologies of elements at risk and the approach used for the derivation of fragility curves. The most common way to define earthquake consequences is a classification in terms of the following *damage states*: *no damage*; *slight/minor*; *moderate*; *extensive*; *complete*. The number of damage states is variable and is related with the functionality of the components and/or the repair duration and cost.. These correlations provide quantitative measures

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of the component's performance, and can be applied for the definition of specific Performance Indicators (PIs), which are introduced in the systemic analysis of each network.

The definition and consequently the selection of the damage thresholds, i.e. limit states, are among the main sources of uncertainties. A considerable effort has been made in SYNER-G to homogenize the criteria as much as possible, while also discussing the different approaches or assumptions made by different researchers.

INTENSITY MEASURES

A main issue related to the fragility curves is the selection of an appropriate earthquake Intensity Measure (IM) that characterizes the strong ground motion and best correlates with the response of each element, for example, building, pipeline orharbour facilities like cranes. Several measures of the strength of ground motion (IMs) have been developed. Each intensity measure may describe different characteristics of the motion, some of which may be more adverse for the structure or system under consideration. Optimum intensity measures are defined in terms of practicality, effectiveness, efficiency, sufficiency, robustness and computability (Mackie and Stojadinovich, 2003).

The selection of the intensity parameter is also related to the approach that is followed for the derivation of fragility curves and the typology of element at risk. Empirical fragility functions are usually expressed in terms of the macroseismic intensity defined according to the different Macroseismic Scales, namely, EMS, MCS, and MM. Analytical or hybrid fragility functions are, on the contrary, related to instrumental IMs, which are related to parameters of the ground motion (PGA, PGV, PGD) or of the structural response of an elastic SDOF system (spectral acceleration S_a or spectral displacement S_d, for a given value of the period of vibration T). When the vulnerability of elements due to ground failure is examined (i.e. liquefaction, fault rupture, landslides) permanent ground deformation (PGD) is the most appropriate IM.

METHODOLOGIES FOR DERIVING FRAGILITY FUNCTIONS

There are several methods available and used in the literature to derive fragility functions for different elements exposed to seismic hazard and in particular to transient ground motion and permanent ground deformations due to ground failure. Conventionally, they are classified into four categories: empirical, expert elicitation, analytical and hybrid. All these approaches have their strengths and weaknesses. However, analytical methods, validated with large-scale experimental data and observations from recent strong earthquakes have become more popular in recent years.

Empirical methods are based on post-earthquake surveys and observations of actual damage. They are specific to particular sites and seismotectonic, geological and geotechnical conditions, as well as the properties of the damaged structures. Consequently, the use of these functions in different regions is always questionable. In case of pipelines the empirical fragility functions relate the repair rates (RR) expressed as repairs/km with the peak ground velocity (PGV) or permanent ground deformation (PGD). *Expert judgment fragility curves* are based on expert opinion and experience. Therefore, they are versatile and relatively fast to establish, but their reliability is questionable because of their dependence on the experiences of the experts consulted. *Analytical fragility curves* adopt damage distributions simulated from the analyses of structural models under increasing earthquake loads. In general they result in a reduced bias and increased reliability of the vulnerability estimates for different structures compared to expert opinion and thus they are becoming ever more attractive in terms of the ease and efficiency by which data can be generated. *Hybrid methods* combine any of the above-mentioned techniques in order to compensate for their respective drawbacks. Finally, the fragility functions of complex components that consist of different sub-components (e.g. hospital facilities, water or waste water treatment plants and pumping stations) are derived based on *fault tree analyses*. The above methods are further described and discussed in Rossetto et al. (2014).

Several uncertainties are introduced in the process of constructing a set of fragility curves of a specific element at risk. They are associated to the parameters of fragility curves, and to the derivation methodology, as well as in the relationship between physical damage state and performance of the element at risk. In general, the uncertainty of the fragility parameters is estimated through the standard deviation, β_{tot}, that describes the total variability associated with each fragility curve. Three primary sources of uncertainty are usually considered, namely, the definition of damage states, β_{DS}, the response and resistance (capacity) of the element, β_C, and the earthquake input motion (demand), β_D. The total variability is modelled by the combination of the three contributors, assuming that they are stochastically independent and lognormally distributed random variables.

FRAGILITY FUNCTION MANAGER TOOL

A fragility function manager tool has been developed for buildings and bridges (Silva et al. 2014). This tool is able to store, visualize, harmonize and compare a large number of fragility functions sets. For each fragility function set, the metadata of the functions, representative plots and the parameters of the functions can be visualized in an appropriate panel or window. Once the fragility functions are uploaded, the tool can be used to harmonize and compare the curves. In Figure 1 the screenshot of the main window of the tool is presented together with a brief description of its principal panels.

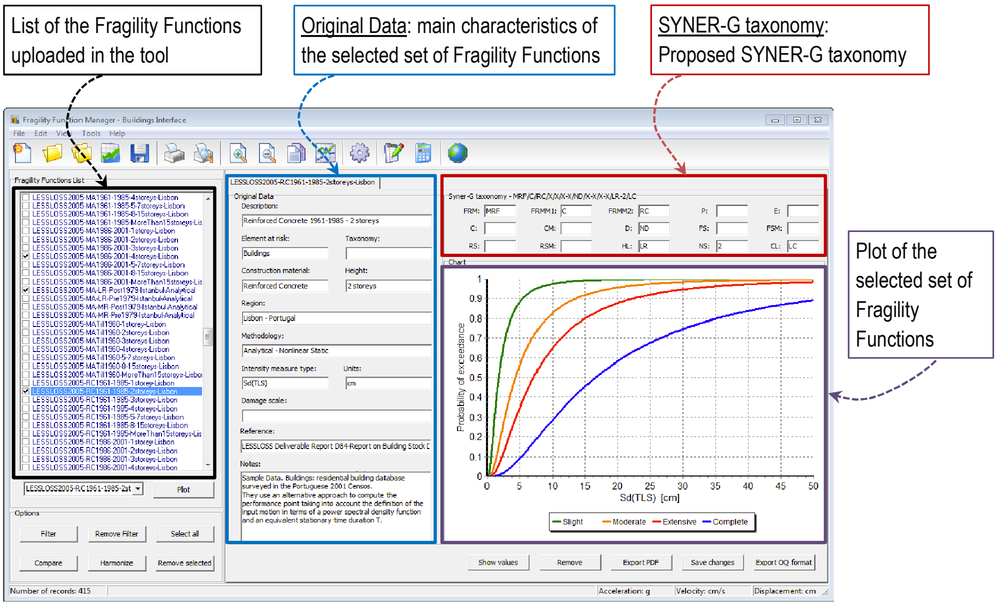

Figure 1. Screenshot of the main window of the Fragility Function Manager tool.

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