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SYNER-G: Typology Definition and Fragility Functions for Physical Elements at Seismic Risk

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Preface

Modern societies and economies become more complex and at the same time more sophisticated. Still, the experience from earthquakes reveals that even the developed societies are quite vulnerable, although the provisions against seismic hazards have been considerably improved. Their exposure to seismic risk in prone seismic areas rely on an *integrated seismic risk approach*, which should define accurately the physical seismic risk and the socio-economic vulnerability and resilience. *Physical seismic risk* is defined with the probability of damages and loss to structures and people due to an earthquake of any intensity. *Socio-economic vulnerability* is the expected impact of a given earthquake on the society and the economy. *Resilience* is the capacity of a society and economy to cope with earthquake events. The physical risk assessment depends on the *seismic hazard*, which expresses the probability of ground shaking and induced phenomena i.e. liquefaction, fault crossing, landslides due to earthquakes, the *exposure* of the different assets and the *physical vulnerability* of the exposed elements at risk, which is the vulnerability of structures, their occupants and services to seismic hazard.

A critical component of this chain of seismic risk assessment is the definition and evaluation of the so-called *fragility functions* or *fragility curves*. They provide the necessary link between seismic hazard assessment at a site and the corresponding effects on any kind of exposed structures i.e. buildings, infrastructures, utilities, lifelines and industrial facilities. The majority of currently available approaches to assess the potential losses for a wide group of exposed elements rely on the availability of relevant fragility curves. In the past decades, the field of seismic risk assessment has witnessed remarkable developments.

SYNER-G is a research project funded by European Commission in the frame of FP7 Theme 6: Environment. The objective of SYNER-G is to develop an integrated methodology and the necessary tools for the systemic seismic vulnerability and risk analysis of complex systems exposed to earthquake hazard, like buildings, and aggregates in urban scale, lifelines, transportation and utility networks, gas and electric power systems, critical facilities, and infrastructures. Interactions between different components and systems are considered in the analysis, as they may increase considerably the global vulnerability and risk of the systems or the system

of systems. SYNER-G methodology encompasses in an integrated way all aspects in the chain, from hazard to the physical vulnerability and loss assessment of components and systems and to the socio-economic impacts of earthquakes, accounting for all relevant uncertainties within an efficient quantitative simulation scheme, modeling interactions between the multiple components and systems.

In the frame of this large collaborative project, an extensive literature review of fragility functions for all elements at risk has been made. Based on a new taxonomy and typology that considers the distinctive European features, existing fragility curves and associated uncertainties have been critically reviewed and new or existing fragility curves have been proposed.

The book presents in a comprehensive way the latest developments on the fragility functions encompassing the work done in SYNER-G and in some other parallel projects, as for example in case of masonry buildings. It is organized in several chapters devoted to different systems. For each system, the new taxonomy and classification scheme is presented and then, after a review of the existing fragility functions, the most relevant fragility functions, new ones and selected from the international literature, for the different components are highlighted. Uncertainties are discussed throughout the book and in particular at the beginning, where the framework of the treatment of uncertainties in view of the construction of fragility functions is outlined. Recommendations are also provided for the selection of the most adequate fragility functions. A special tool has been also developed in the frame of SYNER-G to store, visualize and manage a large number of fragility function sets. The tool can store functions for a wide range of elements at risk, and has features that allow these functions to be harmonized in terms of intensity measure type and limit state. The tool is provided, together with a collection of European fragility functions for buildings, as an electronic supplement to this book (extras.springer.com).

The ambition is to offer to the European and international scientific and engineering community a standard reference book of the present state of the art in fragility models for the seismic risk analysis of most elements at risk, and at the same time to highlight the remaining gaps and the necessary future developments on this important topic. The present book is the first of the two volumes that present the main achievements and results of SYNER-G. The second one entitled *Systemic Seismic Vulnerability and Risk Assessment of Complex Urban*, *Utility*, *Lifeline Systems and Critical Facilities. Methodology and Applications*, demonstrates the integrated methodological framework of SYNER-G, which is applied in selected case studies, also using fragility curves that are included in the present book.

The Editor would like to acknowledge the contributors to the individual chapters who are listed under each chapter. Most of them actively participated in SYNER-G. In particular special acknowledgement to Sergio Lagomarsino, Serena Cattari, Tiziana Rossetto and Dina D'Ayala, who without being partners in SYNER-G accepted the invitation to contribute to this volume.

Finally, the support of the two co-editors, Helen Crowley and Amir M. Kaynia, and in particular the devotion and hard work of Dr. Sotiris Argyroudis to the preparation of this volume is gratefully acknowledged.

Thessaloniki, Greece K. Pitilakis

Contents

1 Introduction 1
Kyriazis Pitilakis, Helen Crowley, and Amir M. Kaynia

2 Modeling and Propagation of Uncertainties 29
Paolo Emilio Pinto

3 Evaluation of Existing Fragility Curves 47
Tiziana Rossetto, Dina D'Ayala, Ioanna Ioannou, and Abdelghani Meslem

4 Epistemic Uncertainty in Fragility Functions for European RC Buildings 95
Helen Crowley, Miriam Colombi, and Vitor Silva

5 Fragility Functions of Masonry Buildings 111
Sergio Lagomarsino and Serena Cattari

6 Fragility Functions of Electric Power Stations 157
Francesco Cavalieri, Paolo Franchin, and Paolo Emilio Pinto

7 Fragility Functions of Gas and Oil Networks 187
Pierre Gehl, Nicolas Desramaut, Arnaud Réveillère, and Hormoz Modaressi

8 Fragility Functions of Water and Waste-Water Systems 221
Kalliopi Kakderi and Sotiris Argyroudis

9 Fragility Functions of Road and Railway Bridges 259
Georgios Tsionis and Michael N. Fardis

10 Fragility Functions of Highway and Railway Infrastructure 299
Sotiris Argyroudis and Amir M. Kaynia

11 Fragility Functions of Harbor Elements 327
Kalliopi Kakderi and Kyriazis Pitilakis

12 Component Fragilities and System Performance of Health Care Facilities 357
Alessio Lupoi, Francesco Cavalieri, and Paolo Franchin

13 Fragility Function Manager Tool 385
Vitor Silva, Helen Crowley, and Miriam Colombi

14 Recommendations for Future Directions in Fragility Function Research 403
Kyriazis Pitilakis and Helen Crowley

Subject Index 415

List of Acronyms

AC	Asbestos cement
AC	Alternating current
BCL	Bars-connecting line
BDG	Buildings
BN	Bayesian networks
BS	Bar systems
C	Concrete
CI	Cast iron
CIDH	Cast-in-drilled-holes
CCD	Central composite design
CoV	Coefficient of variation
CSM	Capacity spectrum method
DBV	Displacement based vulnerability
DI	Ductile iron
DM	Damage state
DS	Damage state
DVE	Damage value
EC2	Eurocode 2
EC8	Eurocode 8
EDP	Engineering demand parameter
EMS98	European Macroseismic Scale
EPN	Electric power network
EPG	Emergency power generator
EQL	Equivalent linear analysis
FE	Finite element
FFM	Fragility function manager
ffs	Fragility function set
FS	Factor of safety
FOSM	First order second moment method
GEM	Global earthquake model
GMICEs	Ground motion to intensity conversion equations

GMPE	Ground motion prediction equations
GIS	Geographical information systems
GMPGV	Geometric mean of PGV
HDPE	High density polyethylene
IDA	Incremental dynamic analysis
IGMCEs	Intensity to ground motion conversion equations
IM	Intensity measure
IML	Intensity measure level
IMT	Intensity measure type
ISDR	Inter-story drift ratio
IO	Immediate Occupancy
JMA	Japan Meteorological Agency
LHS	Latin hypercube sampling
LN	Lognormal
LS	Limit state
MBSR	Matrix-based system reliability methods
MC	Monte Carlo
MCS	Mercalli-Cancani-Sieberg intensity scale
MDOF	Multi degree of freedom
MDPE	Medium density polyethylene
MMI	Modified Mercalli intensity
MSK81	Medvedev-Sponheuer-Karnik Intensity Scale
MV-LV	Medium voltage – low voltage
MRI	Mean return interval
NDA	Nonlinear dynamic analysis
NSA	Nonlinear static analysis
NLTHA	Non-linear time history analysis
OLE	Operating level earthquake
PBVA	Performance based vulnerability assessment
PI	Performance indicator
PGA	Peak ground acceleration
PGD	Permanent ground deformation
PGV	Peak ground velocity
PGS	Peak ground strain
PE	Polyethylene
PLS	Performance limit states
POSA	Push over static analysis
PSI	Parameterless scale of intensity
PVC	Polyvinyl chloride
RC or R/C	Reinforced concrete
RMS	Root mean square of the acceleration
SCADA	Supervisory control and data acquisition
SDOF	Single degree of freedom
SM	Simplified method

SSWP	Strong spandrels weak piers
TGD	Transient ground deformation
ULS	Ultimate limit state
UPS	Uninterruptible power system
WS	Welded steel
WSSP	Weak spandrels strong piers
WSAWJ	Welded-steel arc-welded joints
WSCJ	Welded-steel caulked joints
WSGWJ	Welded-steel gas-welded joints