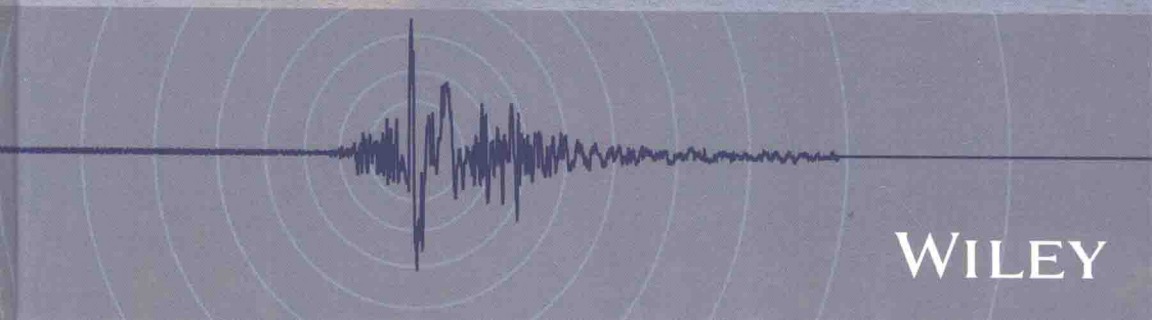
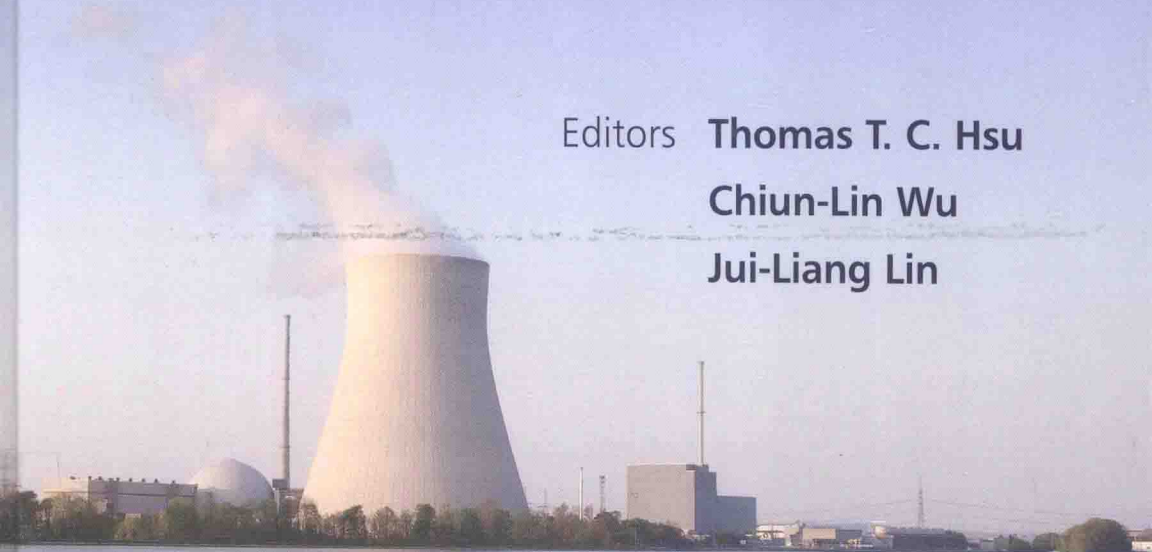


INFRASTRUCTURE SYSTEMS FOR NUCLEAR ENERGY

Editors **Thomas T. C. Hsu**
Chiun-Lin Wu
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Preface

Creating sufficient energy resources to replace traditional, carbon-polluting coal and oil is a crucial question for the health of Planet Earth and the survival of human beings. We are at the cross-roads of deciding whether the unlimited potential of nuclear energy should be utilized. The 2011 Fukushima accident re-opened in the public's mind the question: "Are nuclear power plants safe?" This book intends to sort out the facts from the fallacies on nuclear infrastructures.

This book, *Infrastructure Systems for Nuclear Energy*, addresses both the design and analysis of infrastructures associated with nuclear energy. It first leads readers through an overview of the current/future nuclear power industry and its infrastructure systems. To achieve a comprehensive overview, we invited contributions from the world's top authorities in key areas of expertise, such as regulations, operation, engineer practices, teaching and research. Only through open sharing of scientific studies, not emotional conjecture, can real consensus based on knowledge be built.

This book then provides a thorough investigation of containment structures, nuclear waste storage facilities, and the associated applications of selected commercial/academic computer softwares. Further chapters are devoted to the behavior of infrastructure systems when they are challenged by specific environment issues faced by nuclear power plants, such as the impact of high temperatures, irradiation effects, blasts, earthquakes, soil-structure interaction effects, and so on.

The authors of the book's 31 chapters come from all over the world and are leaders at the cutting edges of their professions. This book, therefore, not only represents the state-of-the-art of nuclear infrastructure systems, but also serves as an authoritative guide for teaching, research, and training of engineers and scientists of the future. This book will serve readers from diverse disciplines and backgrounds. For clarity and convenience, we provide a list of acronyms and their fuller definitions.

This book is the result of institutional cooperation between the University of Houston THSRL (Thomas T. C. Hsu Structural Research Laboratory) in the USA and NCREE (National Center for Research on Earthquake Engineering) of Taiwan. This cross-continent collaboration gave impetus to the signing of an Agreement of Scholarly Exchange and Collaboration in 2001 that was renewed in 2006 and 2011.

The editors would like to thank Professors Shyh-Jiann Hwang, Liang-Jenq Leu, Kuo-Chun Chang, and Chien-Chz Hsu of the National Taiwan University and NCREE for

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Thomas T. C. Hsu
Chiun-Lin Wu
Jui-Liang Lin
July 4, 2013

Acronyms

		Chapters
10 CFR	Title 10 of the Code of Federal Regulations	19
3D	Three Dimension	16
A		
ABWR	Advanced Boiling Water Reactor (light-water cooled)	2
ACI	American Concrete Institute	18, 19, 28
AEC	Atomic Energy Council, Taiwan	7, 29, 30
AFNR	Advanced Fast Neutron spectrum Reactor (sodium cooled)	2
AGR	Advanced Gas-cooled Reactor (carbon dioxide cooled)	2
AIJ	Architectural Institute of Japan	15
ALWR	Advanced Light-Water Reactor	2
AMP	Aging Managing Programs	2
ANS	American Nuclear Society	28
AOS	Add-On-Shield	30
ASCE	American Society of Civil Engineers	5
ASME	American Society of Mechanical Engineers	7, 18, 19, 26, 28
ASP	Aging Surveillance Programs	2
B		
BARC, India	Bhabha Atomic Research Centre in India	24
BDBE	Beyond Design-Basis Earthquake	5
Breeders-FBRs	See FBR	2
BWR	Boiling Water Reactor	1, 2, 10, 16, 17, 28
BWRVIP	Boiling Water Reactor Vessel and Internals Project	7
C		
C	Celsius	19
CAMUS	French Seismic Research Program	8

CANDU	CANada Deuterium Uranium (reactor) (heavy water moderated)	2
CCF	Common-Cause Failure	2
CDF	Core Damage Frequency	2
CEA	French Atomic Agency; Also, French Alternative Energies and Atomic Energy Commission	8
CFR	Code of Federal Regulations	1, 18, 28, 31
CO ₂	Carbon Dioxide	2
CONMOD	CONcrete containment MODeling and management	28
CPR	Chinese (design) Pressurized (light-water cooled) Reactor	2
CRWMS M&O	Civilian Radioactive Waste Management Systems, Management and Operating contractor	31
D		
DBA	Design-Basis Accident	17
DBE	Design-Basis Earthquake	5, 30
DBGM	Design-Basis Ground Motions	31
DID	Defense-In-Depth	2
DM	Direct Method	22
DNBM	Department of Nuclear Backend Management	29
DOD	Department of Defense	17
DOE	Department of Energy	1, 9, 17, 31
E		
E/B	External Building	10
EACD	Earthquake Analysis of Concrete Dams, a computer program developed at the University of California, Berkeley	23
EBS	Engineered Barrier System	31
ECCS	Emergency Core Cooling Systems	1, 2
EPR	European (evolutionary) Pressurized (light-water cooled) Reactor, a third-generation PWR	1, 2, 22
EPRI	Electric Power Research Institute	7, 21, 28
EPU	Extended Power Up-rate	2
ESBWR	Economic Simplified Boiling Water Reactor (light-water cooled)	2
ESI	Effective Seismic Input	23
ETH Zurich	Eidgenössische Technische Hochschule Zürich, Swiss Federal Institute of Technology, Zurich	24
EUR	European Utility Requirements	22
EW	East–West	16
F		
F	Fahrenheit	19
FBR	Fast (neutron spectrum) Breeder Reactor	2
FE	Finite Element	22

FEM	Finite Element Method	16
FEP	Features, Events, and Processes	29
FSAR	Final Safety Analysis Report	30
FTS	Free Thermal Strain	26
G		
GALL	Generic Aging Lessons Learned	28
GDC	General Design Criteria, or General Design Criterion	1, 18, 19
GE	General Electric Company	2
GEH	GE-Hitachi nuclear energy co.	2
GEL	Green Energy and Environment Research Laboratories	29
GGE	Greenhouse Gas Emission	2
GWh	GigaWatt-hour (10^9 W-hour)	2
H		
HCLPF	High-Confidence-Low-Probability of Failure	3, 5
HDB	High-Damping rubber Bearing	5
HE	High-Explosive	17
HF	High-Frequency	19
HLW	High-Level Waste	31
I		
I/C	Inner Concrete	10
IAEA	International Atomic Energy Agency	1, 2, 28
IED	Improvised Explosive Device	17
ILRT	Integrated Leakage Rate Test	1
INER	Institute of Nuclear Energy Research, Taiwan	29, 30
IPP	Independent Power Producers	6
iPWR	integrated PWR	9
ISFSI	Independent Spent Fuel Storage Installation	30
ISG	Interim Staff Guidance used by the Spent Fuel Project Office of US Nuclear Regulatory Commission	19, 22
ITRI	Industrial Technology Research Institute	29
ITS	Important To Safety	31
ITWI	Important To Waste Isolation	31
J		
JEAG	Japan Electric Association Guidelines	5, 15
JMA	Japan Meteorological Agency	16
JNES	Japan Nuclear Energy Safety Organization	5
JRC	Joint Research Centre, European Commission	8
K		
KEPCO	Kansai Electric Power Company	10
KEPRI	Korea Electric Power Research Institute	15
KK	Kashiwazaki-Kariwa NPP	16

KM	Knowledge Management	2
KSSC	Korean Society of Steel Construction	15
kWh	kiloWatt-hour (10^3 W-hour)	2
L		
LCS	Large-Core Solution	22
LDB	Low-Damping rubber Bearing	5
LITS	Load-Induced Thermal Strain	26
LLNL	Lawrence Livermore National Laboratory	23
LLRT	Local Leakage Rate Test	1
LOCA	Loss-Of-Coolant Accident	1, 2
LR	License Renewal	2
LRB	Lead-Rubber Bearing	5
LSTC	Livermore Software Technology Corporation	23
LTO	Long-Term Operation	2
LWR	Light-Water Reactor	27
M		
MAFE	Mean Annual Frequency of Exceedance	3
MCMC	Markov Chain Monte Carlo	8
METI	Ministry of Economy, Trade and Industry, Japan	10
MLIT	Ministry of Land, Infrastructure, Transport and tourism, Japan	10
MSM	Modified Subtraction Method	22
MUR	Measurement Uncertainty Recapture	6
MUR PU	Measurement Uncertainty Recapture Power Up-rate	2
MWd	MegaWatt-day	2
MWe	MegaWatt-electrical	2
MWh	MegaWatt-hour (10^6 W-hour)	2
N		
NCO	Niigataken Chuestu-Oki earthquake	16
NEA	Nuclear Energy Agency	2, 28
NEUP	Nuclear Energy University Program	1
NGNP	Next Generation Nuclear Plant	2
NI	Nuclear Island	22
NISA	Nuclear and Industrial Safety Agency, Japan	10
NPP	Nuclear Power Plant	2, 3, 6, 16, 24, 27, 28, 30
NRC	Nuclear Regulatory Commission, See US NRC	1, 2, 9, 17, 18, 19, 31
NS	North-South	16
NSC	Nuclear Safety Commission of Japan	10
NSSS	Nuclear Steam Supply System	6
NUPEC	Nuclear Power Engineering Cooperation, Japan	17, 21
O		
O&M	Operation and Maintenance	2
OBE	Operating-Basis Earthquake	19

OECD	Organization of Economic Cooperation and Development (Europe)	2
OFR	Office of Federal Regulations	28
OPs	Operational Practices	2
ORNL	Oak Ridge National Laboratory	26
P		
PCR/V	Pre-stressed Concrete Reactor Vessel	26
PGA	Peak Ground Acceleration	3, 8, 31
PGV	Peak Ground Velocity	31
PHWR	Pressurized Heavy-Water Reactor (CANDU)	2
P-I	Pressure-Impulse	17
PLiM	Plant Life Management program	2
PLM	Plant Life Management	27
PML	Perfectly Matched Layer	23
pp fibers	Polypropylene fibers. The recommended volume content of 0.1% pp fibers is approximately a dosage of 0.9 kg/m ³ monofilament	25
PRA	Probabilistic Risk Assessment	2
PRM	Pontiroli, Rouquand, Mazars damage model	8
PSHA	Probabilistic Seismic Hazard Analysis	3, 5
psig	pounds per square inch, gauge	19
PSR	Periodic Safety Review	2
PT	Penetrant Test	30
PU	Power Up-rate	2
PVP	Pressure Vessels and Piping	26
PWh	PetaWatt-hour (10 ¹⁵ W-hour)	2
PWR	Pressurized Water Reactor	1, 2, 9, 10, 17, 28
Q		
QA	Quality Assured	2
R		
R.G.	Regulatory Guide	28
R/C	Reinforced Concrete	10
RB	Reactor Building	30
RBMK	Reaktor Bolshoy Moschnosti Kanaliy (Russian high power channel-type reactor)	2
RCCV	Reinforced Concrete Containment Vessel	10, 21
RGs	Regulatory Guides	19
RH	Relative Humidity	8
RILEM	International Union of Laboratories and Experts in Construction Materials, Systems, and Structures	28
RIP	Reactor Internal Pump	2
RPV	Reactor Pressure Vessel	2
RT	Radiographic Test	30

S

S/G	Steam Generators	10
SA	Spectral Acceleration	31
SAR	Safety Analysis Report	30
SASSI	System for Analysis of Soil–Structure Interaction, a computer program	22
SDC	Seismic Design Category	5
SFP	Spent Fuel Pool	1, 30
SG	Steam Generator	9
SKM	SKin Method	22
SM	Subtraction Method	22
SMiRT 18	18th International Conference on Structural Mechanics in Reactor Technology	19
SMR	Small Modular Reactor	9
SNF	Spent Nuclear Fuel	31
SNL	Sandia National Laboratories	17, 31
SPRA	Seismic Probabilistic Risk Assessment	3
SPU	Stretch Power Up-rate	2
SRV	Steam Relief Valve	2
SSC	Structures, Systems, and Components (in NPPs)	1, 28
SSCs	see SSC	2, 19
SSE	Safe-Shutdown Earthquake	19
SSHAC	Senior Seismic Hazard Analysis Committee	3
SSI	Soil–Structure Interaction	16, 19, 22, 30
SSSI	Structure–Soil–Structure Interaction	19

T

TEPCO	Tokyo Electric Power Company	10
TEV	Transport and Emplacement Vehicle	31
TFR	Transfer Cask	30
TG/DTA	Thermogravimetry and Differential Thermal Analysis	27
TMSL	Tokyo Mean Sea Level	10
TPC	Taiwan Power Company	7, 29, 30
TPRI	Taiwan Power Research Institute	29
TSC	Transportable Storage Canister	30
TSPA	Total System Performance Assessment	31
TTC	Transitional Thermal Creep	26
TWh	TeraWatt-hour (10^{12} W-hour)	2

U

UD	Up–Down	16
UHRs	Uniform Hazard Response Spectrum	5
UO ₂	Uranium Dioxide	2
US DOE	United States Department Of Energy	28
US NRC	United States Nuclear Regulatory Commission	5, 21, 28
UT	Ultrasonic Test	30

V		
VCC	Vertical Concrete Cask	30
VHTR	Very High Temperature Reactor	2
VVER	Vodo-Vodyanoi-Energetichesky-Reactor; See WWER	2
W		
WANO	World Association of Nuclear Operators	6
Wh	Watt-hour	2
WSCP	Water and Soil Conservation Plan	30
WWER	Water-cooled, Water-moderated light water Reactor (Russian design of a PWR); See VVER	2

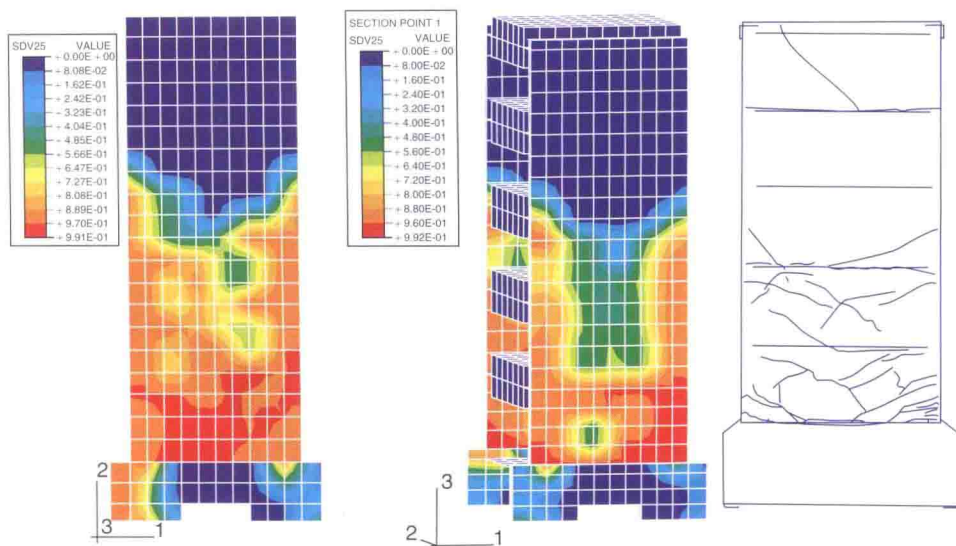


Figure 8.8 Predicted tensile damage contours after the Nice 1.0g earthquake and the corresponding crack pattern

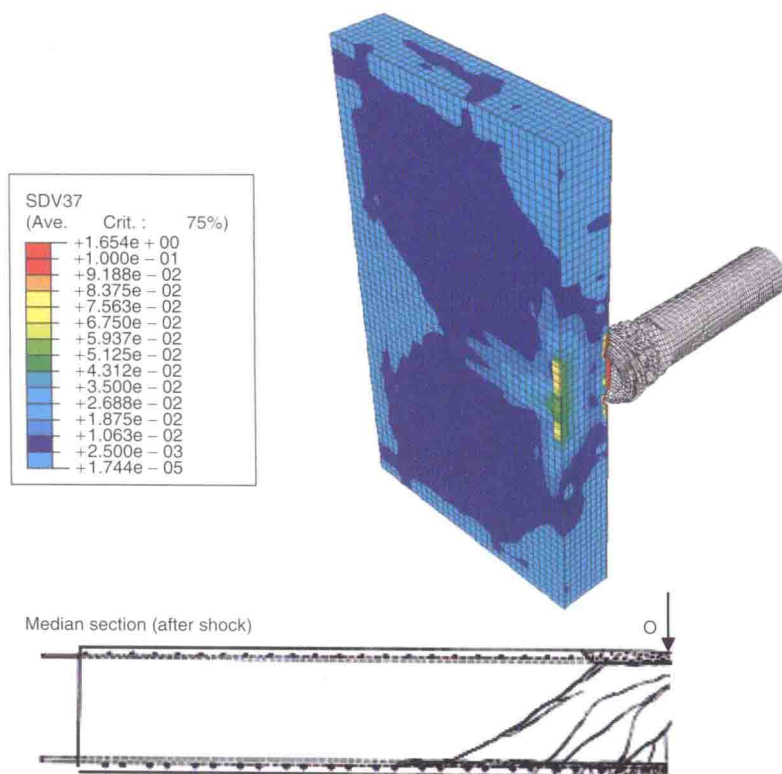


Figure 8.11 Test no. 12: comparison between computed and observed damages