



Sven Klinkel · Christoph Butenweg
Gao Lin · Britta Holtschoppen *Editors*

Seismic Design of Industrial Facilities

Proceedings of the International Conference
on Seismic Design of Industrial Facilities
(SeDIF-Conference)

SeDIF  Conference

 Springer Vieweg

Sven Klinkel · Christoph Butenweg ·
Gao Lin · Britta Holtschoppen
Editors

Seismic Design of Industrial Facilities

Proceedings of the International
Conference on Seismic Design of Industrial
Facilities (SeDIF-Conference)



Springer Vieweg

CHAIR OF
STRUCTURAL STATICS AND DYNAMICS
RWTHAACHEN



Editors

Sven Klinkel
Lehrstuhl für Baustatik u. Baudynamik
RWTH Aachen
Aachen, Germany

Christoph Butenweg
Lehrstuhl für Baustatik u. Baudynamik
RWTH Aachen
Aachen, Germany

Gao Lin
Faculty of Infrastructure Engineering
Dalian University of Technology No.2
Dalian City, China

Britta Holtschoppen
Lehrstuhl für Baustatik u. Baudynamik
RWTH Aachen
Aachen, Germany

ISBN 978-3-658-02809-1

ISBN 978-3-658-02810-7 (eBook)

DOI 10.1007/978-3-658-02810-7

Library of Congress Control Number: 2013947577

Picture Credits for this book cover (from left to right): Lanxess AG, AkzoNobel, BASF SE, LBB (RWTH Aachen Univ.), BASF SE

Springer Vieweg

© Springer Fachmedien Wiesbaden 2014

This work is subject to copyright. All rights are reserved, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilm or in any other way, and storage in data banks. Duplication of this publication or parts thereof is permitted only under the provisions of the German Copyright Law of September 9, 1965, in its current version, and permission for use must always be obtained from Springer. Violations are liable to prosecution under the German Copyright Law.

The use of general descriptive names, registered names, trademarks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

Printed on acid-free paper.

Springer is part of Springer Science+Business Media
www.springer.com

Seismic Design of Industrial Facilities

Preface

Devastating earthquakes in China (2008 and 2010), New Zealand (2011), Japan (2011) and Italy (2012) have tightened the social and the political focus on the seismic risk emanating from industrial facilities. Seismic Design of Industrial Facilities, however, demands a deep knowledge on the seismic behaviour of the individual structural and non-structural components of the facility, possible interactions and last but not least the individual hazard potential of primary and secondary damages.

From 26.–27. September 2013 the International Conference on Seismic Design of Industrial Facilities firstly addresses this broad field of work and research in one specialized conference. It brings together academics, researchers and professional engineers in order to discuss the challenges of seismic design for new and existing industrial facilities and to compile innovative current research.

This volume contains more than 50 contributions to the SeDIF-Conference covering the state of the art of international building codes and guidelines of seismic design of industrial facilities, seismic design of structural and non-structural components, seismic design of liquid-filled tanks and other contained structures, seismic safety evaluation of existing structures, uncertainty and reliability analysis, latest retrofitting measures and innovative seismic protection systems as well as theoretical and practical approaches in investigation of soil-structure-interaction effects.

We thank all authors for their varied and highly interesting contributions showing the broad field of work and auspicious new research activities regarding seismic design of industrial facilities.

Aachen, Germany
September 2013

Prof. Sven Klinkel
Prof. Gao Lin

Dr. Christoph Butenweg
Dr. Britta Holtschoppen

Acknowledgements

The SeDIF-Conference is hosted by the Chair of Structural Statics and Dynamics of RWTH Aachen University, Germany, in cooperation with the Institute for Earthquake Engineering of the Dalian University of Technology, China.

Organising Committee of the SeDIF-Conference and Editors of the Proceedings:

Prof. Sven Klinkel	RWTH Aachen University
Prof. Gao Lin	Dalian University of Technology
Dr. Christoph Butenweg	RWTH Aachen University
Dr. Britta Holtschoppen	RWTH Aachen University

The SeDIF-Conference is supported by the DFG (Deutsche Forschungsgemeinschaft). This support is greatly acknowledged by the organising committee.

The organising committee would also like to express their gratitude to the scientific committee of the SeDIF-Conference:

Prof. Elena Dumova	(Univ. SS. Cyril and Methodius, Skopje, MK)
Prof. Mario Duran Lillo	(Univ. La Serena, Chile)
Prof. Mihail Garevski	(IZIIS-Skopje, Macedonia)
Prof. Linhai Han	(Tsinghua Univ., Beijing, China)
Prof. Sven Klinkel	(RWTH Aachen University, Germany)
Prof. Carsten Könke	(Bauhaus-Univ. Weimar, Germany)
Prof. Jie Li	(Tongji Univ., China)
Prof. Gao Lin	(Dalian University of Technology, China)
Prof. em. Konstantin Meskouris	(RWTH Aachen University, Germany)
Dr. Philippe Renault	(swissnuclear, Switzerland)
Prof. Stavros Savidis	(TU Berlin, Germany)
Prof. Chongmin Song	(Univ. of New South Wales, Australia)
Prof. Demosthenes Talaslidis	(Aristotle University Thessaloniki, Greece)

Content

Part I Vulnerability of Industrial Facilities

Earthquake Damage and Fragilities of Industrial Facilities	3
Mustafa Erdik, Eren Uckan	

Part II Seismic Risk of Industrial Facilities

Seismic Risk Analysis of an Oil-Gas Storage Plant	17
Roberto W. Romeo	

Site-Specific Seismic Hazard Assessment	27
Timo Schmitt	

Critical Industrial Facilities: Simply Applying Current Importance Factors γ_I is not Enough!	37
Martin G. Koller and Ehrfried Kölz	

Part III International Building Codes and Guidelines

Overview of Seismic Regulations for French Industrial Facilities	55
Pecker Alain	

Seismic Design of Industrial Facilities in Germany	63
Christoph Butenweg, Britta Holtschoppen	

Precast Industrial Buildings in Italy Current Building Code and New Provisions Since the 2012 Earthquake	75
Marco Mezzi, Fabrizio Comodini, Leonardo Rossi	

Part IV Seismic Safety Evaluation and Retrofitting

Earthquake Assessment of Existing Chemical Production Facilities	89
T. Drommer, C. Gellert	

Probabilistic Seismic Analysis of Existing Industrial Facilities	101
Hamid Sadegh-Azar, Truong-Diep Hasenbank-Kriegbaum	
Uncertainty Propagation in Engineering Systems: Probability Density Evolution Theory and Its Recent Developments	113
Jie Li	
Elliptical Response Envelopes for the Design of Reinforced Concrete Structures: New Developments and Application to Nuclear Power Plant Buildings	131
Quang Sang Nguyen, Silvano Erlicher, François Martin	
Improvement of Seismic Response of an Industrial Structure	143
Milan Sokol, Rudolf Ároch	
Part V Innovative Seismic Protection Systems	
International Fusion Reactor Tokamak Complex Seismic Isolation	157
Stéphane Cazadiou, Laurent Patisson, Sébastien Diaz	
Strategies for the Seismic Protection of Power Plant Equipment	169
Peter Nawrotzki, Daniel Siepe	
MARMOT – A Certified Seismic Monitoring System for Vulnerable Industrial Facilities	177
Andreas Stiegler, Hans-Jürgen Nitzpon, Werner Bolleter	
Automatic or Manual Safe Shutdown of Industrial Facilities on Earthquake Signal, Guidelines to Meet the New French Regulation: Seismological and Instrumental Aspects	187
Fabrice Hollender, Jean-Philippe Girard, Didier Girard, Sébastien Sauvignet and the AFPS working group for the Guidelines “Automatic or manual safe shutdown...”	
Experimental Study on Seismic Behaviour and Vibration Control of Wind Turbine and Electrical Transmission Tower	197
Bin Zhao, Taixiu Cui, Zhuang Xu, Yilong Cao	
Part VI Seismic Design of Secondary Structures	
Systemic Seismic Vulnerability and Risk Analysis of Urban Systems, Lifelines and Infrastructures	209
Kyriazis Pitilakis, Sotiris Argyroudis	

Floor Response Spectra Considering Influence of Higher Modes and Dissipative Behaviour	235
Marius Pinkawa, Benno Hoffmeister, Markus Feldmann	
Application and Distinction of Current Approaches for the Evaluation of Earthquake-Response of Secondary Systems	247
Wehr, Franziska, Bach, Andreas, Zahltan, Wolfhard	
Seismic Design of Mechanical and Electrical Components According to Safety Standard KTA 2201 of the German Nuclear Safety Standards Commission	259
Matthias Wacker	
Seismic Qualification of Equipment in Industrial Facilities	271
Carsten Block, Thomas Bauer, Fritz-Otto Henkel	
Shake Table Test on the 1:30 Model Structure of A Large Cooling Tower for Fire Power Plant	281
J. W. Dai, X. R. Wengand Y. Hu	
Seismic Qualification of Electrical Cabinets	295
Marcus Ries, Helmut Kennerknecht, Philipp Moor, Fritz-Otto Henkel	
Seismic Design of Fastenings with Anchors in Nuclear Power Plants	305
Rüdiger Meiswinkel, Franz-Hermann Schlüter	
New European Seismic Regulations Provide Guidance for the Qualification and Design of Post-installed Anchoring	315
J. Gramaxo, M. Di-Sario	
Fastenings for Use in Concrete – Seismic Actions	327
Wolfgang Roeser	
Part VII Seismic Design of Primary Structures	
Reliability Analysis on Capacity Design Rules for Steel Frames	337
Max Gündel, Benno Hoffmeister, Markus Feldmann	
Dissipative Devices for Vulnerability Reduction of Precast Buildings	349
Marco Mezzi, Fabrizio Comodini, Leonardo Rossi	
Seismic Performance of Concrete-Filled Steel Tubular (CFST) Structures	361
Lin-Hai Han, Wei Li	
System Identification of Industrial Steel Building Based on Ambient Vibration Measurements and Short Time Monitoring	369
Sergey Churilov, Simona Markovska, Elena Dumova-Jovanoska, Goran Markovski	

Collapse Simulation of Building Structures Induced by Extreme Earthquakes	381
Xinzheng Lu, Xiao Lu and Linlin Xie	

Part VIII Seismic Design of Silos, Tanks and Vessels

The Eurocode Approach to Seismic Design of Liquid-Filled Steel Storage Tanks	391
Margarita Chasapi	

Lateral Free Vibration of Liquid-Storage Tanks	403
Konstantinos Mykoniou, Britta Holtschoppen	

Seismic Design of Spherical Pressure Vessels	417
Matthias Wieschollek, Marius Pinkawa, Benno Hoffmeister and Markus Feldmann	

Seismic Isolation of Cylindrical Liquid Storage Tanks	429
Julia Rosin, Thomas Kubalski, Christoph Butenweg	

A Comparison of Piping Stress Calculation Methods Applied to Process Piping System for Seismic Design	441
Cheng Weimin, Jopp Heiko, Jan Pekař	

Seismic Analysis of Pressure Vessels in Correspondence to the VCI-Guideline	451
Jörg Habenberger, Sebastian Villiger	

Seismic Assessment of Horizontal Cylindrical Reservoirs	461
Christos Baltas, Pierino Lestuzzi, Martin G. Koller	

Part IX Soil-Structure Interaction: Applications

The Significance of Site Effect Studies for Seismic Design and Assessment of Industrial Facilities	475
Corinne Lacave, Martin G. Koller Pierino Lestuzzi and Christelle Salameh	

Soil Liquefaction: Mechanism and Assessment of Liquefaction Susceptibility	485
Roberto Cudmani	

Seismic Design and Verification of a Nuclear Power Plant Structure for the Storage of Radioactive Waste Components	499
Davide Kurmann, Zdenek Janda and Jan Cervenka	

Seismic Analysis of Onshore Wind Turbine Including Soil-Structure Interaction Effects	511
Francesca Taddei, Konstantin Meskouris	

Part X Soil-Structure Interaction: Scientific Approaches

Dynamic Impedance of Foundation on Multi-Layered Half-Space	525
Gao Lin	
The Scaled Boundary Finite Element Method for Transient Wave Propagation Problems	547
Carolyn Birk, Denghong Chen, Chongmin Song and Chengbin Du	
Attenuation of Ground-borne Vibrations Induced by Underground Dynamic Excitation	557
Tong Jiang	
Boundary Effects on Seismic Analysis of Multi-Storey Frames Considering Soil Structure Interaction Phenomenon	569
Kemal Edip, Mihail Garevski, Christoph Butenweg, Vlatko Sesov, Julijana Bojadjeva and Igor Gjorgjev	
Response Analysis of a Long-span Arch Bridge under the Seismic Travelling Wave Excitation	577
Menglin Lou, Qiang Li and Shan Gao	
A 3D Dynamic Impedance of Arbitrary-Shaped Foundation on Anisotropic Multi-Layered Half-Space	591
Gao Lin, Zejun Han	
Two Parameters to Improve the Accuracy of the Green's Functions Obtained via the Thin Layer Method	603
Lin Chen	
Time Domain Analysis of Dynamic Response for 3D Rigid Foundation on Multi-layered Soil	615
Zejun Han, Gao Lin, Jianbo Li	
Eta-based Conditional Mean Spectrum, a New Design Spectrum for Industrial Facilities	627
Alireza Azarbakht	
Trade Exhibition SeDIF-Conference	637

Earthquake Damage and Fragilities of Industrial Facilities

Mustafa Erdik¹, Eren Uckan¹

¹ Kandilli Observatory and Earthquake Research Institute / Bogazici University,
Istanbul, erdik@boun.edu.tr

ABSTRACT:

An industrial facility consists of many integrated components and processes. As such, operation of a facility depends upon the performance of its critical components. The greatest risk from an earthquake is that to life safety. However, in large earthquakes, industrial buildings and related machinery and equipment damaged may be costly to repair and there may be additional damage from fire and chemical spills. As such, the design (or seismic retrofit) of industrial facilities should preferably be based on performance-based methodologies with the objective of controlling structural and non-structural damage and the triggered technological disasters. In this paper industrial damages and losses that took place in past important earthquakes, especially in the 1999 Kocaeli earthquake, will be summarized. A general description of industrial-sector and component based earthquake performance and vulnerabilities will be provided.

Keywords: industry, seismic risk, fragility, damage.

1 Introduction

Earthquakes world over, such as 1994 Northridge-USA, 1995 Kobe-Japan, 1999 Kocaeli-Turkey, 2008 Wenchuan-China, 2010 Chile, 2011 Tohoku-Japan and 2011 Van-Turkey earthquakes, have resulted in significant loss of life and property as well as extensive losses to industry. In all these earthquakes older, heavy industrial facilities, especially those with taller structures that partially to totally collapsed, were more affected by the earthquake than newer facilities. It was observed that any type and quality of anchorage improved the performance of machines and equipment, except very sensitive equipment such as assembly line sensors in the automotive industry and rotary kilns in cement plants. Losses associated with business interruption were more severe for these types of facilities. For light industrial facilities, building damage turned out to be the primary reason for direct and indirect losses. For refineries and other chemical processing facilities, non-building structures turned out to be the most vulnerable, with tanks being the most susceptible to earthquake and fire damage. Large storage tanks, pipelines,

transmission lines and precision machinery were generally susceptible to damage. Port and harbour facilities are particularly susceptible to sub-marine landslides or ground settlement due to liquefaction that may occur during earthquakes. In addition, all processes that involve a substantial risk of explosion such as those in the petrochemical industry and processes involving molten metal.

Fragility functions of an element at risk represent the probability that its response to earthquake excitation exceeds its various performance (damage) limit states based on physical considerations. Fragility assessments are usually based on past earthquake damages (observed damage and, to a lesser degree, on analytical investigations).

The 1999 Kocaeli earthquake (Mw7.4) is considered the largest event to have damaged an industrialized area since the 1906 San Francisco and 1923 Tokyo earthquakes (Unless referenced otherwise, the information regarding the 1999 Kocaeli earthquake is adopted from Erdik and Durukal [6]).

The epicenter of the 1999 Kocaeli earthquake was the main site of Turkey's heavy industry. Major industries exposed included: automobile manufacturing; petrochemicals; motor and railway vehicle manufacture and repair; basic metal works; production and weaving of synthetic fibers and yarns; paint and lacquer production; tire manufacturing; paper mills; steel pipe production; pharmaceuticals; sugar processing; cement production and power plants. It was observed that any type and quality of anchorage improved the performance of machine and equipment except very sensitive equipment, such as assembly line sensors in case of automotive industry and rotary kilns in cement plants. For the case of light industrial facilities in the earthquake area, the building damage turned out to be primary reason for direct and indirect losses. In the case of refineries and other chemical processing facilities, non-building structures turned out to be vulnerable with tanks being the most susceptible ones to earthquake and fire damage. The extend of the damage was attributed to the duration and long period motion of the earthquake MCEER(14).

2 Sector Based Description of Earthquake Performance and Damage

2.1 Petrochemical Industry

In 1999 Kocaeli earthquake an extensive concentration of petrochemical complexes are located within 5 km of the causative fault. The earthquake caused significant structural damages to the Tüpraş refinery itself and associated tank farm with crude oil and product jetties. The consequent fire in the refinery and tank farm caused extensive damage. There was damage to cooling towers and the port area. Collapse of a 150m high heater stack on the boiler and crude oil processing unit caused significant damage and started a second fire Figure 1. The total damage is estimated to be around US\$350 million. Fault rupture and soil failure caused extensive damage to pump station and pipelines at about 20 locations. The failure of the water supply caused problems in controlling the fire. There were at least 15 gas firms with spherical LPG storage tanks in the area. No major structural damage

was observable at these plants (EERI [4]). Being unanchored some tanks slid horizontally on their supports.



Figure 1: Damaged tanks at tank farm (left) and collapsed stack at TÜPRAS Refinery

2.2 Automotive Industry

The Hyundai car factory experienced significant non-structural damage to its air handling systems, cable trays and shearing of bolted connections in the steel structure EERI [4], Figure 2.



Figure 2: Equipment damage at Hyundai-Assan car factory (after Milli-Re)

In Toyota car factory there was little structural damage to the steel framed buildings, two buildings experienced damage to their columns. Non-structural damage included collapsed storage racks, transformers, cars on the assembly line, sliding of the cooling tower associated with pipe damage. Ford Otosan car factory, under construction during the earthquake, experienced significant terrain subsidence and some structural damage Figure 3.



Figure 3: Damaged prefabricated buildings at Ford Otosan Plant

2.3 Other Industry

In 1999 Kocaeli earthquake the TUVASAS railway wagon, Adapazari sugar and steel production factories have received extensive structural damage. Examples of specific damage included collapse of cranes, roof collapse, transformer damage, silo collapse, toxic releases from mixing chemicals, and collapse of liquid oxygen tank support structures. Some tanks in Aksa chemical installation in Yalova experienced damage, which was associated with leakage of chemicals. Numerous industrial facilities experienced losses of stored items Figure 4.

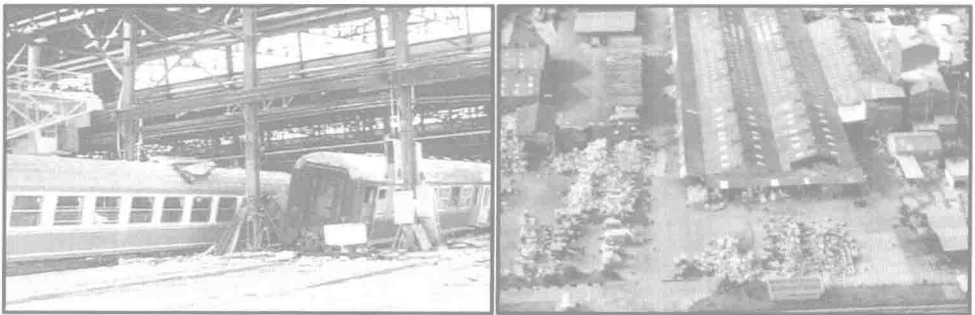


Figure 4: Damaged steel structure at Adapazari rail car factory (left) and losses of open stored materials