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

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CHAIR OF STRUCTURAL STATICS AND DYNAMICS
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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

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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-Confer covering the state of the art of international building codes and guidelines o seismic design of industrial facilities, seismic design of structural and structural components, seismic design of liquid-filled tanks and other contained structures, seismic safety evaluation of existing structures, uncerta and reliability analysis, latest retrofitting measures and innovative se 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 sho the broad field of work and auspicious new research activities regarding seismic design of industrial facilities.

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Prof. Sven Klinkel
Prof. Gao Lin

Dr. Christoph Butenweg
Dr. Britta Holtschoppen

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Prof. Gao Lin	Dalian University of Technology
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Dr. Britta Holtschoppen	RWTH Aachen University

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Content

Part X Soil-Structure Interaction: Scientific Approaches

Part I

Vulnerability of Industrial Facilities

Earthquake Damage and Fragilities of Industrial Facilities

Mustafa Erdik[1], **Eren Uckan**[1]

[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,

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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 Tupras 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 slided horizontally on their supports.

Figure 1: Damaged tanks at tank farm (left) and collapsed stack at TÜPRAŞ 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.

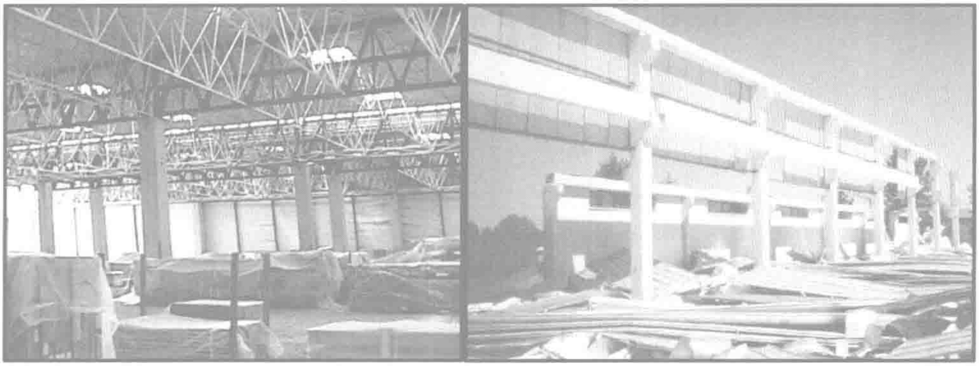

Figure 3: Damaged prefabricated buildings at Ford Otosan Plant

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