E203

Analysis of Earthquake-Induced Natech Events: A Monte Carlo-Markov Chain Methodology for Storage Tank Accident Sequence Modeling and Industrial Downtime Estimation

（地震誘発ナテック現象の分析：貯蔵タンク事故シーケンスモデリング及び操業停止時間推定のためのモンテカルロ・マルコフ連鎖手法）

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This research focuses on earthquake-induced Natech accidents in chemical industrial parks, specifically targeting the domino effects involving industrial storage tanks. Utilizing a Monte Carlo-Markov Chain method, the study analyzes the impacts of earthquakes on storage tanks and simulates subsequent domino effect scenarios. The methodology incorporates factors such as thermal radiation, shockwave overpressure, and uses historical data to develop recovery curves. The aim is to evaluate the probability of tank damage and the duration of industrial downtime. Additionally, a case study of a storage tank farm at the Cosmo refinery in the Osaka Sakai area is conducted. This case focuses on understanding the implications of accident chain development on the outcomes of tank-related incidents. The study's approach provides insights into disaster resilience planning, emphasizing the importance of dynamic consequence analysis for industrial facilities prone to earthquake-induced accidents.

1. Introduction

Technological accidents involving the release of hazardous materials triggered by natural hazards are known as Natech accidents (Cruz and Suarez, 2019). For instance, during the Great East Japan Earthquake in 2011, severe fires and explosions at refineries in Sendai and Chiba led to a series of cascading incidents, known as the domino effects. Accidents involving domino effects represent low-probability, high-consequence incidents that can cause severe damage to people, property, and the environment. Despite the potential for escalation in Natech accidents induced by earthquakes, the inherent domino effect is often overlooked in plant engineering and design processes. Dynamic consequence analysis offers a rational approach for risk assessment and management due to the extensive and uncontrollable nature of domino effects. Analyzing the coupling of multi-physical fields in domino effect propagation can enable a more accurate study of accident escalation. Modeling or assessing the evolution of domino events is crucial for protecting chemical and process facilities from the impacts of cascading accidents.

In the context of earthquake hazard, resilient systems or subsystems are defined by lower failure likelihood and consequences. This includes the probability of earthquakes, structural damage patterns, and the likelihood of their outcomes (Petak, 2002) Downtime, as a measure of industrial accident impacts from natural disasters, is a key aspect of industrial resilience.

2. Research Purpose

Numerous cases have shown that natural disasters can cause significant damage to hazardous facilities, leading to severe consequences. This is particularly pertinent in earthquake-prone Japan, where studying the safety risks to industrial facilities posed by earthquakes is crucial. In the context of frequent disasters, Misuri *et al.* (2021) emphasize the importance of researching cascading accidents triggered by natural disasters to enhance disaster preparedness and mitigation. The presence of cascading accidents means that allowing disaster chains to develop can result in extremely serious consequences. Current studies on Natech events' domino phenomena mainly focus on the transmission mechanisms and probabilities of accidents between units. Although various methods and studies exist for estimating infrastructure downtime, very few focus on downtime caused by disasters and accidents.

The purpose of this study is to investigate earthquake-induced Natech accident chains and their dynamic consequence analysis through the development of an accident simulation model to quantify their probabilities and restoration times.

3. Methodology and model development

The dynamics of an earthquake related Natech accident at an industrial park can follow the pathways as shown in Fig. 1. The proposed model must then consider various issues as discussed below.

a) Earthquake effects: This study uses an earthquake along the Nankai Trough in Japan as a reference scenario for our case study, and the Next Generation Attenuation (NGA) ground motion prediction equations (GMPE) to forecast seismic parameters for the tanks. Furthermore, peak ground acceleration (PGA) and earthquake damage probability curves are used to determine the probability of tank damage.

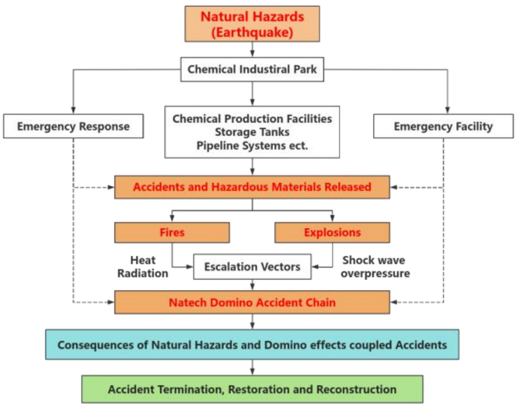

Fig. 1. The flow path of an earthquake-related Natech.

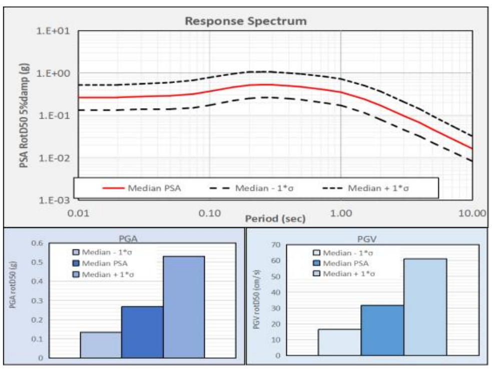

Fig. 2. Prediction of response spectrum in Osaka Area (top), and PGA (bottom left) and PGV (bottom right) for a Nankai trough earthquake using NGA-Subduction Ground-Motion Models.

b) Determining Initial Damage State: We use the HAZUS earthquake loss estimation method developed by FEMA, which provides vulnerability curves for different structures, to determine the initial damage state of tanks during an earthquake.

c)Transition Probability Analysis: We analyze the probability of tank state transitions based on escalation vectors, such as thermal radiation and shockwave overpressure, combined with Probit models.

d) Monte Carlo Sampling Simulation: We use a Monte Carlo sampling method to simulate all possible scenarios under the given conditions and predict the disaster development timeline.

e) Post-Disaster Functionality Quantitative Model: We develop a quantitative model to determine the remaining post-disaster functionality of tanks, incorporating a simplified analysis of the consequences of earthquakes and domino cascading disasters. We use HAZUS restoration curves and Monte Carlo simulations to determine the restoration time distribution for the tank storage area.

f) Case Study: We use predicted PGA data for a major earthquake on the Nankai Trough. The tank area for the case study is selected from the Cosmo refinery in the Osaka Sakai area, with tank layout data derived from Google satellite maps and map measurements.

4. Results and conclusion

This study found that tank farm fire will last 2-3 days when the domino chain is allowed to develop in the worst-case. Early termination of the domino accident chain, such as through emergency operations, would be effective in reducing downtime. The model outputs are shown in Figs. 3 and 4 below.

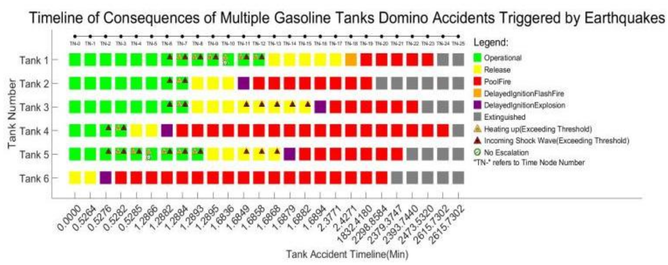

Fig. 3. Simulation of gasoline storage tank domino accidents for one Natech scenario (PGA=0.3g, Terminal Time=infinite).

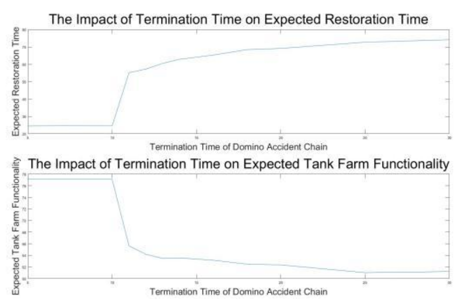

Fig. 4. Analysis of Domino Effect Chain Termination Time on Tank Farm Restoration and Functionality (PGA=0.3g, Terminal Time≤30min).