Earthquake-triggered accidents at industrial facilities: lessons learned from the Wenchuan earthquake

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Characteristics:

- 12 May 2008
- Longmen Shan fault system
- Main shock: $M_w = 7.9$
- Depth 19 km
- Fault rupture > 200 km
- Ground motion duration: 100s
- Max. PGA: 0.96g
- Numerous landslides, rock falls
- Numerous aftershocks ($M > 6$)
Consequences

- Total area affected 500,000 km$^2$
- Casualties: 70,000 dead, many injured
- Building damage: > 5,000,000 buildings collapsed, 21 million suffered damage (from USGS, 2009)
- Extensive damage to lifelines
- Economic losses ca. 140 billion US$ (from P. Shi, 2008)
What about industry?

- Chemical industry in natural-hazard zones: major accident potential with secondary consequences on the surroundings → NATECH accidents

**NATECH**

*Natural-hazard triggered technological accident*

Where “technological accident” is understood as:

- Damage to and hazardous-materials release from fixed chemical plants
- Damage to and release from oil and gas pipelines
NATECH disasters are problematic because:

- Simultaneous response efforts required to cope with both the natural disaster and the technological accident.

- Natural disasters can trigger simultaneous releases from single or multiple sources.

- Lifeline systems needed for accident mitigation unavailable.

- Standard civil protection measures may not be functional or appropriate.

- Safety measures designed to contain hazmat accidents may not be sufficient or appropriate for controlling releases triggered by, and simultaneous with, natural disasters.
- Loss of lifelines; bled out ammonia on a neighboring fertiliser plant
- Many response personnel were unavailable; neighboring community evacuated

- 115 m high stack collapsed
  - 63 product pipelines cut and heating unit damaged
  - Fire in the crude oil unit; valves rendered inoperable so feeders could not be shut off

- Naphtha tank farm
  - Earthquake vibrated floating metal roofs; sparks created; naptha ignition; leak through damaged flange flowed downstream through drainage canals spreading fire to additional tanks.

From L. Steinberg, SMU, USA; 7th IIASA-DPRI Forum, Stresa, IT
• Sichuan Province: many chemical facilities → how did they perform under the earthquake loads?

• Little public information

→ Natech Field visit: 18 facilities
  in Deyang, Shifang, Mianzhu, Mianyang, Anxian, Dujiangyan

Collect data on:
+ Damage to buildings & equipment
+ Safety measures
+ Hazardous-materials releases
Damage to Buildings and Equipment

Destroyed production building
Column failure and building collapse
Collapsed dryer
Vessel collapse and connected pipe breaks
Pipe connection failure

Damage to masonry chimney
Chengdu, 14 July, 2009 – IDRC 2009

• **Structural damage to and collapse** of warehouses, offices and manufacturing buildings was the **main cause of worker death** (> 275 fatalities in 2 heavily damaged plants)

• Old facilities built with **no or little seismic design** were more heavily affected

• **Pipe and equipment damage** or breaking was due to direct earthquake loading, support failure or debris impact

• **Tanks and vessels** were damaged by debris impact, foundation failure or directly by the earthquake forces (liquid sloshing?)

• In some sites **liquefaction-induced damage**
Safety Measures

+ Active and passive safety barriers also affected by the earthquake

+ Bracing of pipes mostly effective in preventing pipe displacement

+ Anchoring of equipment effective
Hazardous-Materials Releases

- Vast number of broken flanges, pipes and vessels → hazmat releases must have occurred
- Ammonia releases in at least 5 facilities → evacuation of 6,000 residents, pollution of a river, damage to crops
- Sulphuric acid spills
- Sulfur burning and explosion
- Phosphorus fires
- Ignition probability high after release of flammable substance during an earthquake (ca. 76%)
• **Direct losses** due to building and equipment damage: probably around 250 million US$ in visited facilities alone

• **Indirect costs** due to plant shutdown and business interruption (also from human losses): unknown

• 6 months after earthquake major repair and reconstruction still underway

• Some companies are moving production away from fault zone
Typical Natech problem: respond to chemical accidents with multiple and simultaneous hazmat releases when emergency response personnel is busy dealing with natural disaster consequences and in the absence of lifelines (water, power) needed for fighting the accident

- Little information on emergency-response performance BUT:
  + prevention/mitigation measures not designed for an earthquake of this magnitude
  + power supply and water service disrupted
  → difficult to contain hazmat releases in hardest-hit facilities under these circumstances
Conclusions

• Natural disasters can have a major impact on industry with possibly serious consequences on man and/or the environment

• Release scenarios: toxic dispersion, fires, explosions

• High PGA areas: building damage dominant, lower PGA areas: equipment damage dominant

• Buildings with some seismic design performed better → importance of implementing seismic building codes

• Realistic assessment of earthquake severity and resultant loading on structure in codes → seismic codes updated

• Wenchuan earthquake damage to industry typical for earthquake-triggered Natechs
THANK YOU
FOR YOUR ATTENTION!

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