Interdisciplinary study on the mitigation of NaTech risks in a complex world: learning from Japan experience applying ERRA NaTech method, iNTeg-Risk project

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Overview/purpose of the project

The 1st objective is to apply ERRA NaTech methodology to tsunami for implementation of risk reduction measures.

The 2nd objective is to assess structural behaviours for facilities under Tsunami, seismic loads or domino effects.

The 3rd objective is to define an integrated policy approach to mitigation of tsunami impact.

The 4th objective is to develop an economic model to assess the vulnerability of supply chain network.

Major Outcomes

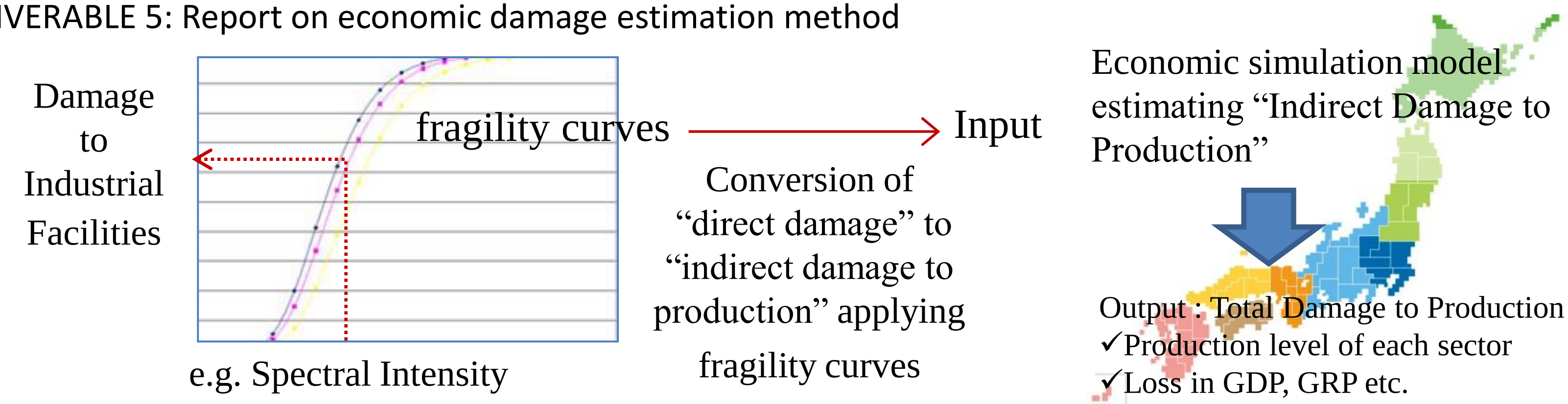
DELIVERABLE 1: Report containing results and analysis of field investigation

DELIVERABLE 2: Report of good practices for the mitigation of tsunami risk

DELIVERABLE 3: Two behaviour models, and fragility curves for generic equipment, and a report containing probability distributions

DELIVERABLE 4: Proposal document of mitigation policy package.

DELIVERABLE 5: Report on economic damage estimation method



Natech is an acronym of **"Natural hazards triggered technological accidents",** which bridges the gap between natural disasters and industrial safety.

Natech is complex in several senses,
Physically (Industrial complex)
Chemically (Many chemicals)
Economically (Supply chain)
Governance (regulatory structure)

Interdisciplinary study on the mitigation of Natech risks in a complex world: learning from Japan experience applying ERRA NaTech method, iNTeg-Risk project

France team
→engineering
Japan team
→Social science

"ERRA" means "Emerging Risks Representative (industrial) Applications".

The 3.11 Earthquake was the ultimate Natech case.

One of the European Commission FP7 projects.
One of 17 case studies (ERRA) was ***Natech***.

Existing Natech research was done with mainly earthquakes, floods, and lightning strikes.
Tsunami is relatively new to Natech community.

Structure of the project

Task 1: Data acquisition (Field investigation)

Task 2: Data analysis

Task 3: Implementation of ERRA Natech method

Task 4: Development of structural behaviour models: deterministic and probabilistic approaches

Task 5: Policy approach to mitigation of tsunami impact

Task 6: Estimation of the economic impact through supply chain network

Task 7: Dissemination

Why is “Natech” so important?

Natech: natural-hazard triggered technological accidents

- Increase of extreme weather events caused by climate change
- Industrialization and urbanization of developing countries
- Widespread of emerging technologies
- Increase in complexity and interconnectedness of society

Organisation for Economic Cooperation and Development

OECD WGCA project

Working Group on Chemical Accident

Control of the Impact of Natural Hazards on Chemical Installations (2008-2012)

Japan failed to respond to a questionnaire concerning the management of Natech conducted in 2009 because no department could deal with Natech.

OECD Workshop

Natech Risk Management

Natural Hazards Triggering Technological Accidents

23 - 25 May 2012, Dresden, Germany

Yuji Wada (AIST) gave a presentation titled "Natech Accidents due to the 11 March 2011 Earthquake and Tsunami and Follow up" in this workshop.

Natech as an “emerging risk”

Early Recognition, Monitoring and Integrated Management of Emerging, New Technology Related Risks

Start/End: Dec.1, 2008 to May 31, 2013 Budget: about 19.3 million €
The number of participants: 414
The number of partner organizations: 58
Coordination: EU-VRI (European Virtual Institute for Integrated Risk Management EEIG, A. Jovanovic)

iNTeg-Risk →integration

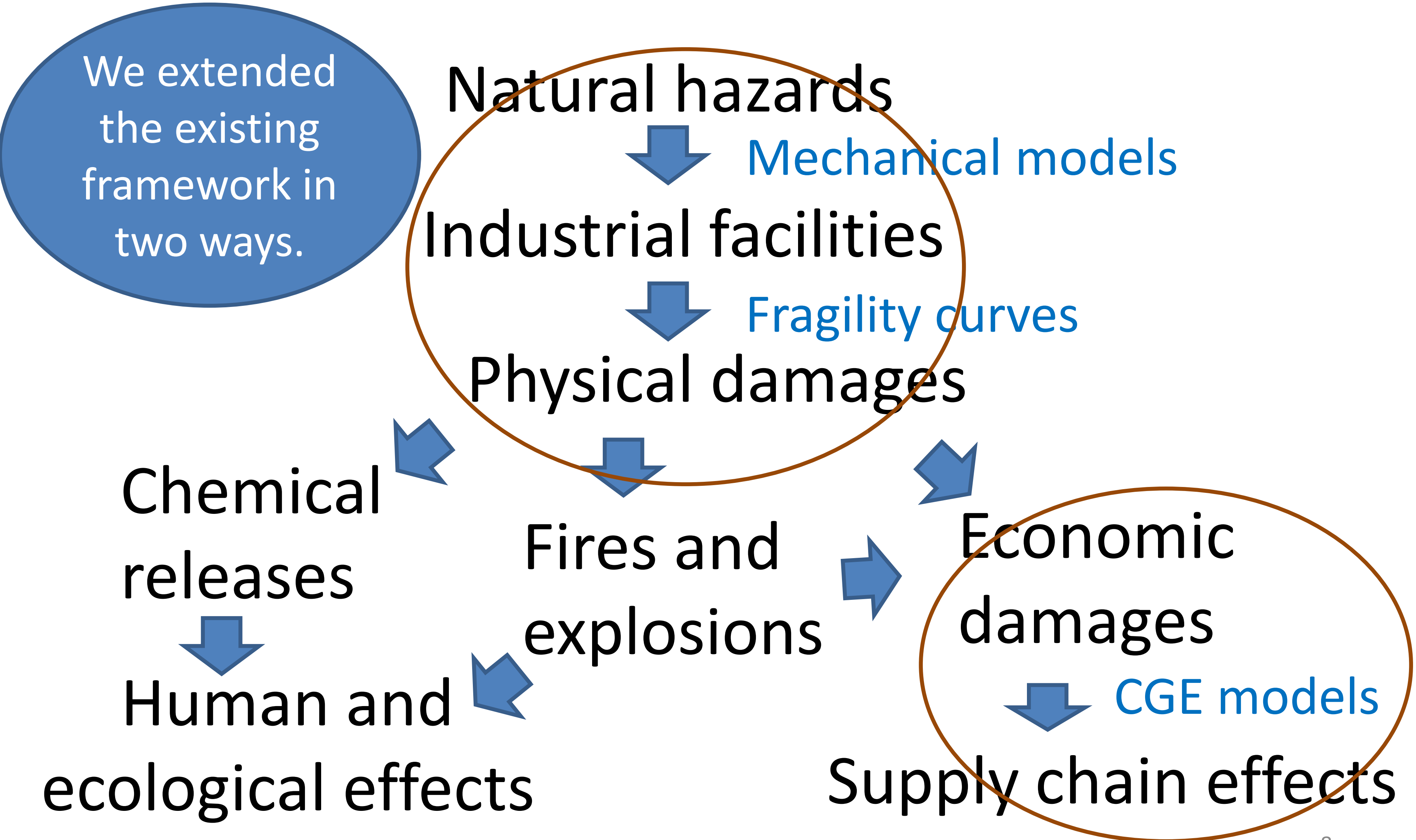
iNTeg-Risk →New technologies

iNTeg-Risk →e(mergin)g

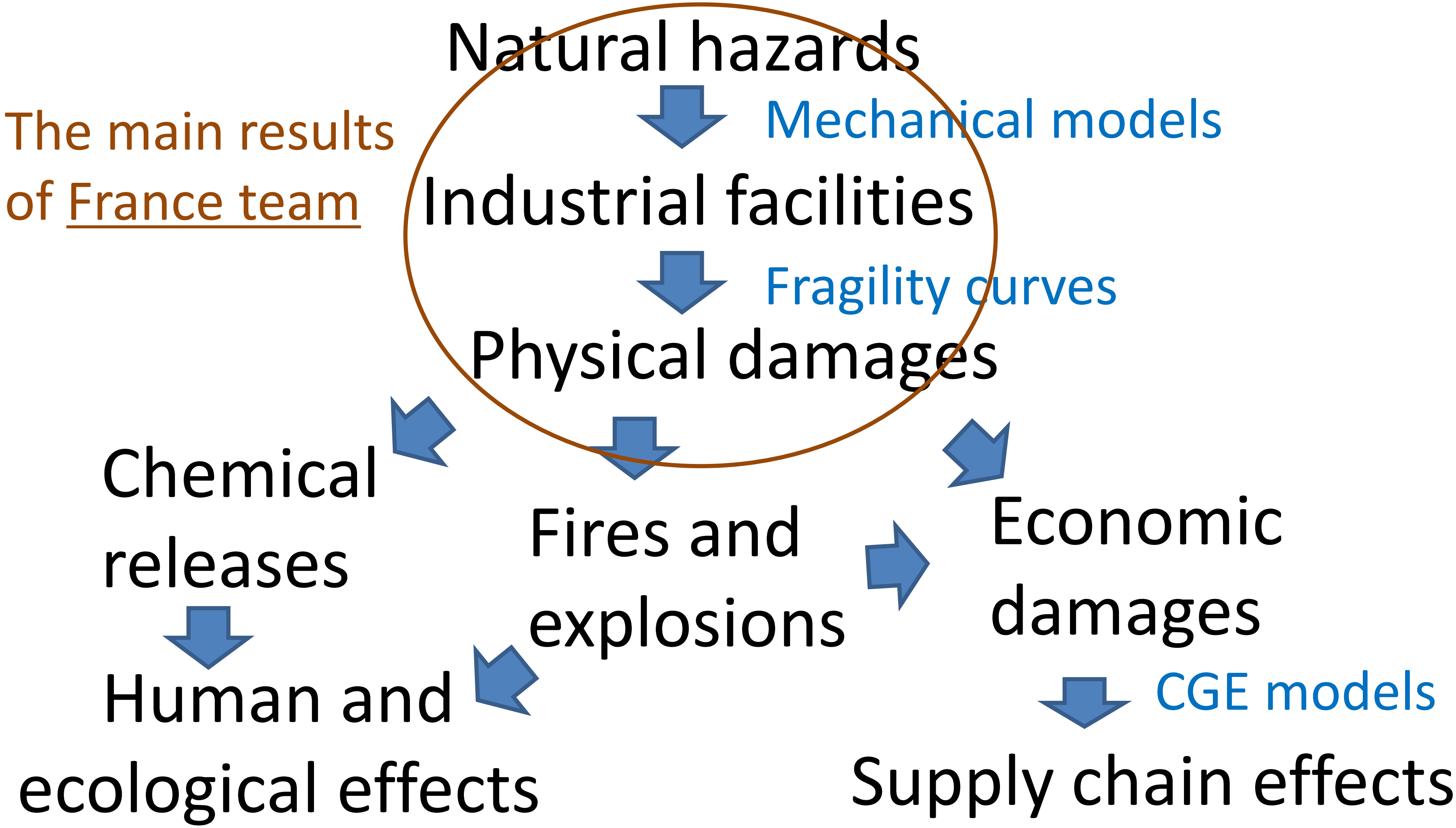
What we have done in INTERNATECH project

- To apply iNTeg-Risk methodology to tsunami for implementation of risk reduction measures.
- To assess structural behaviours for facilities under tsunami, seismic loads or domino effects.
- To develop an economic model to assess the vulnerability of supply chain network.
- To suggest an extended Natech risk analysis framework.

(Extended) Natech risk analysis framework



(Extended) Natech risk analysis framework



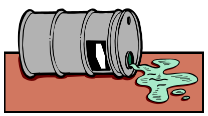
INTERNATECH project: Introduction

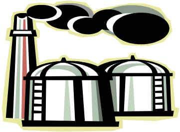
-Combination between natural and technological hazards within industrial plants (NaTech Risks) : Disastrous consequences on installations (hazardous substances, electrical systems, sensors,...)

-Technological accidents triggered by natural disasters => **NATECH accidents**

ERRA NATECH (InTegRisk Project)

-ERRA NATECH : Risk Analysis methodology to define measures preventing NATECH Accidents





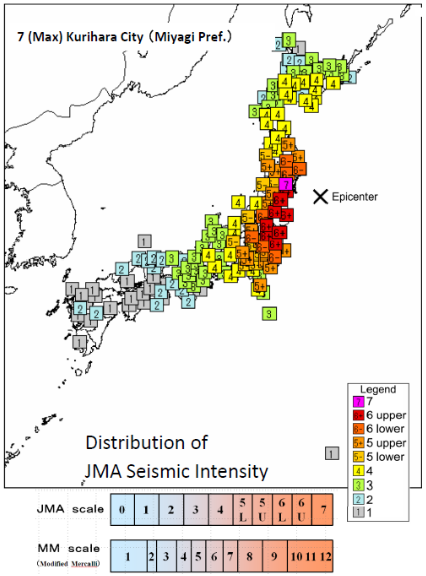
Performing Risk assessment for any industrial process, or activity, likely to present accident risk for workers, public and the environment => commonplace nowadays

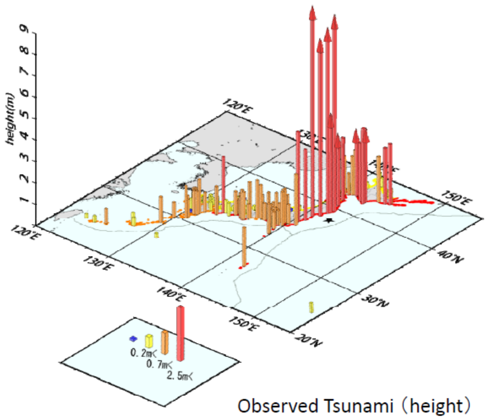
≠

NaTech Risks Evaluation is more difficult =>
- generating realistic sequences of accident events
- Understanding of the collapse mode
- Defining crisis management measures taking the supply chain disruption into account
- Etc…

The project ERRA NATECH provides a methodology enabling a better understanding of causal relations leading up to a NaTech accident

- Earthquake and Tsunami characteristics





Observed Tsunami (height)

Date and Time: 11 March 2011 14:46 JST (05:46 UTC)

Magnitude: 9.0 (the largest earthquake recorded in Japan)

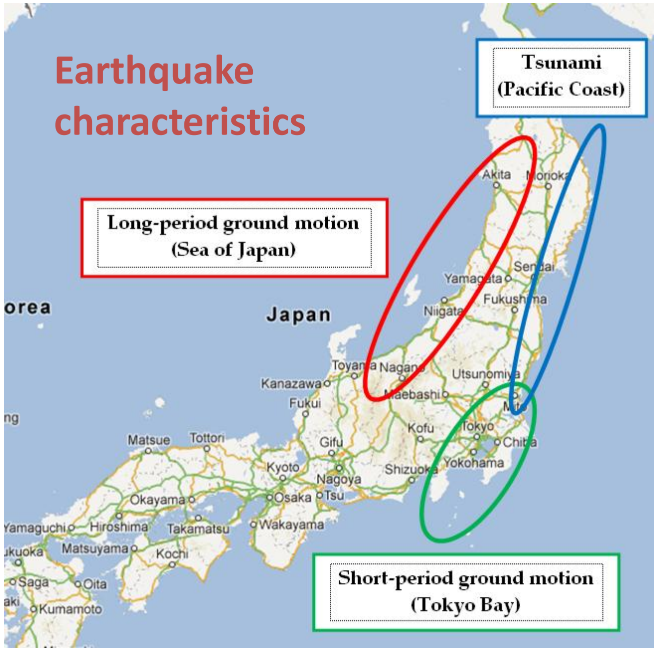
Hypocenter: N38.1, E142.9 Depth 24km (interim value)
(130km ESE off Ojika Peninsula)

Earthquake

- Maximal Seismic Intensity : 7

Tsunami

- 8,5m or higher at Miyako (Iwate Pref.)
- 8,0m or higher at Ofunato (Iwate Pref.)
- 9.3m or higher at Soma (Fukushima Pref.)



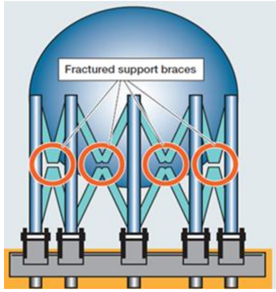
Earthquake consequences

- Pacific coast : Storage tanks damaged (buckling & liquefaction) / pipes (minor damages)
- Tokyo bay : Huge fires in LPG Area – Chiba
- Along the Sea of Japan : Sinking of floatings roofs to storage tanks

Earthquake consequences

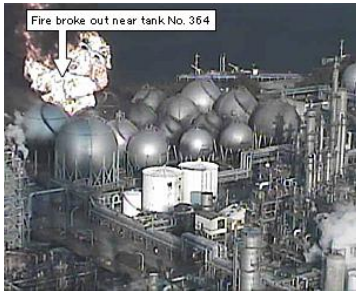
*Boiling liquid expanding vapor explosion

- Collapse of LPG tanks in Chiba Bay



Collapse of one tank filled with water

Rupture of pipes near the tank : Fire

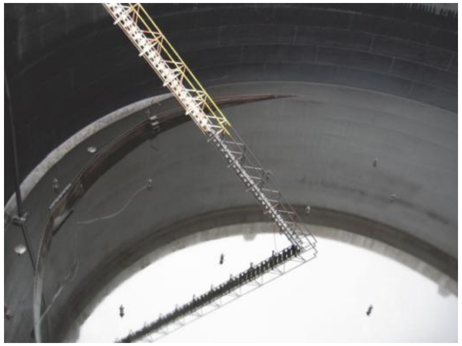


Domino Effects : BLEVE* in the LPG Tank

Fractured support braces collapsed by strength ground motion

- Damage by liquefaction / sloshing effects

Valve in contact to the ground : Asphalt was removed to prevent collapse of the nozzle (liquefaction)



Sinking of floating roof due to sloshing effects

Employees took refuge on the roof after hearing a tsunami warning.

Tanks overturning due to ground motions (near Sendai)

Field Investigations

Tsunami consequences

- Collapse of storage tanks / pipes

Tank washed away by the Tsunami (Miyagi Pref.)

Tank trucks overturned by the tsunami (Sendai JX Nippon Oil refinery)

Tanks damaged by debris impact

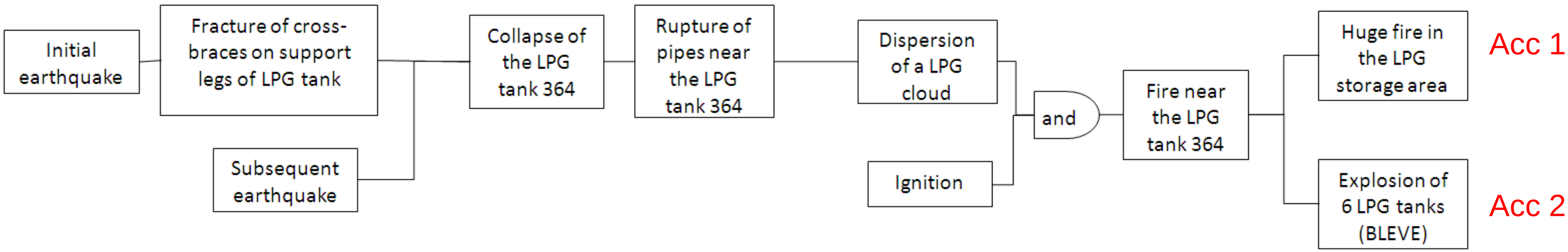
- Environmental consequences

Oil leakage due to collapse of pipelines (Sendai JX Nippon Oil refinery)

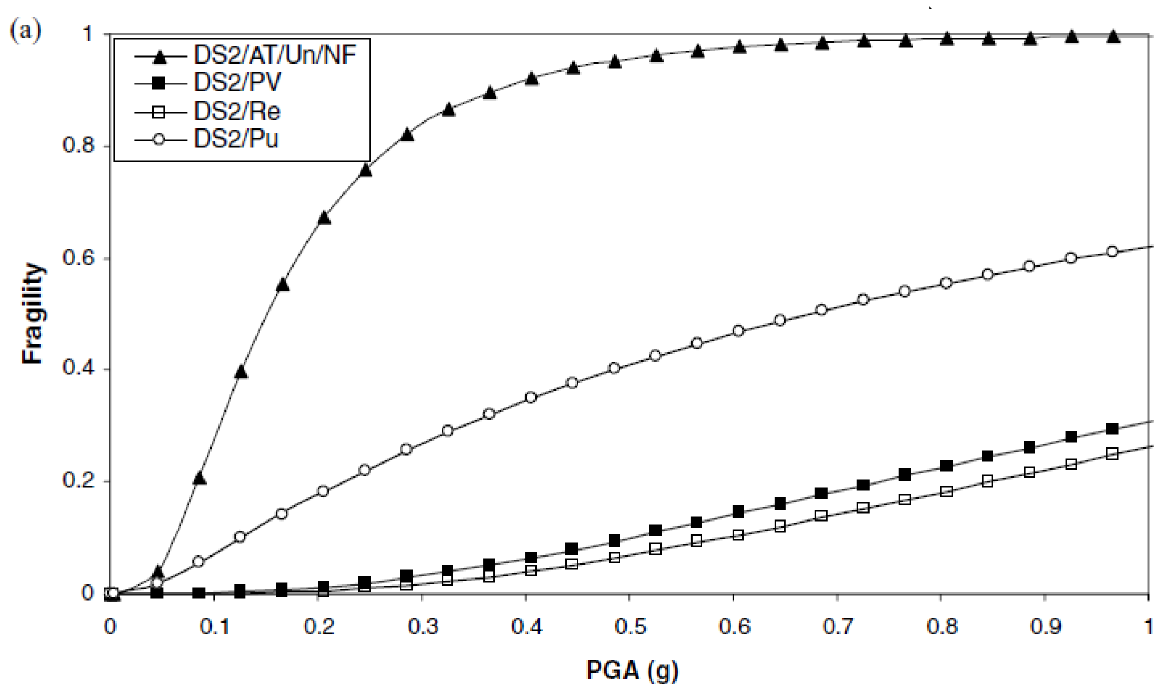
Oil leaked from a refinery at Shiogama bay (Miyagi Pref.)

Application of ERRA to Cosmo Oil Refinery-Chiba

- PGA : 1,3 m/s² (~130 gal) / no casualties, only injured people



- An example of fragility curve to estimate probability failure of pressure tanks regarding PGA Level



Probability of equipment damage : 10^{-2}

This fragility curved deals with pressurized vessel. It is not dedicated to LPG tanks

Application of ERRA to Cosmo Oil Refinery-Chiba

- FOCUS : Position of accident 1 & 2 in the ERRA Natech matrix

Probability

Pf1 x Pf2 : $10^0 \times 10^{-2}$ = **10^{-2}**
Where Pf1 : Probability of earthquake with thios PGA
And Pf2 : Probability of failure (for vessel equipments filled with water)

Severity

Level of gravity of the consequences	*Significant lethal effects (*)*	*Lethal effects(**)*	*Irreversible effects on human life*
Disastrous	More than 10 people exposed	More than 100 people exposed	More than 1000 people exposed
Catastrophic	Less than 10 people exposed	Between 10 and 100 people exposed	Between 100 and 1000 people exposed
Significant	Less than 1 person exposed	Between 1 and 10 people exposed	Between 10 and 100 people exposed
Serious	No one exposed	At least 1 person exposed	Less than 10 people exposed
Moderate	No lethal zone outside the establishment		Human presence exposed to irreversible effects on human life lower than "one person"

Acc 1: Huge fire of the LPG tanks => thermal effects
- 8kW/m² (284m) - 5 kW/m² (321 m) – 3kW/m² (373 m)

Acc 2 : Blast of LPG tanks (BLEVE) => thermal and pressure effects
- thermal effects until 1253 m and blast effects until 286 m

more than 10 people => Disastrous

Application of ERRA to Cosmo Oil Refinery-Chiba

- FOCUS : Position of accident 1 & 2 in the ERRA Natech risk matrix

	10^{-5} E	10^{-4} D	10^{-3} C	10^{-2} B	A
Disastrous				**Acc 1** **Acc2**	
Catastrophic					
Significant					
Serious					
Moderate					

- Conclusion :

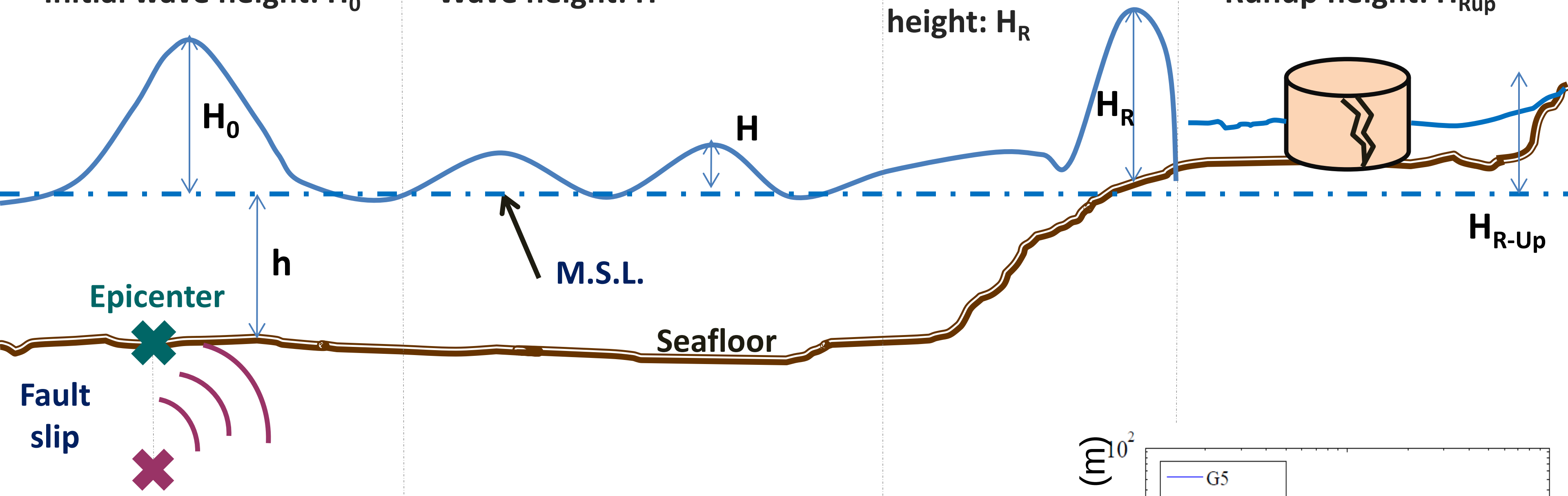
1) Consequences in terms of casualties planned by ERRA Natech methodologies are higher than the findings of the field investigation.
2) Fragility curves to estimate equipment response are too conservative.

➡ **It is necessary to develop fragility curves dedicated to specific equipment (LPG tanks namely) through the implementation of mechanical behaviour models.**

Tsunami model

- Objective : predict wave height at the shoreline

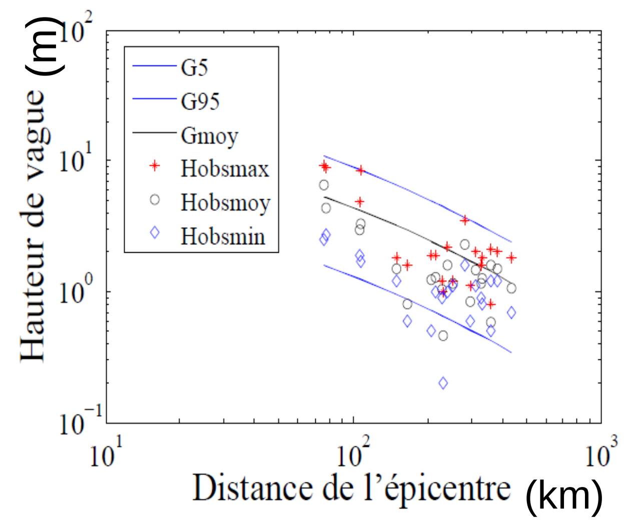
Source parameters	**Far field wave propagation**	**Arriving wave**	**Inland propagation**
Initial wave height: H_0	Wave height: H	Shoreline wave height: H_R	Runup height: H_{Rup}



$$\frac{H}{H_0} = \frac{e^{-\beta R}}{1 + R e^{-(M_W - M_0)}}$$

with

$$\begin{cases} H_0 = 10^{0.5 M_W - 3.3 + C} \\ \beta = 0.00038 \\ M_0 = 3.5 \end{cases}$$



Mechanical models

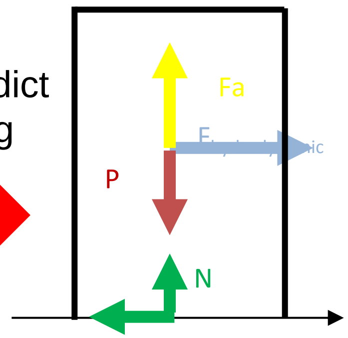
- Objectives :

1) To predict equipment response under seismic / Tsunami loads
2) To build fragility curves that could be used in the framework of ERRA NATECH

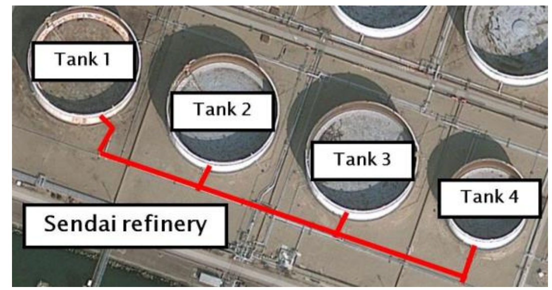
- Tsunami Loads

Collapse Mode : Uplift/Overturning

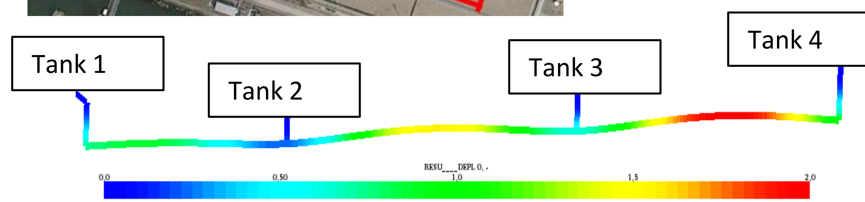
Analytical model developed to predict Uplift/ Overturning



Collapse Mode : Uplifting of pipelines with FEM Analysis

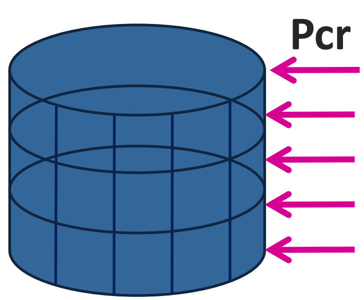


Finite Elements Analysis for studying Pipelines subjected to flooding-Sendai Refinery



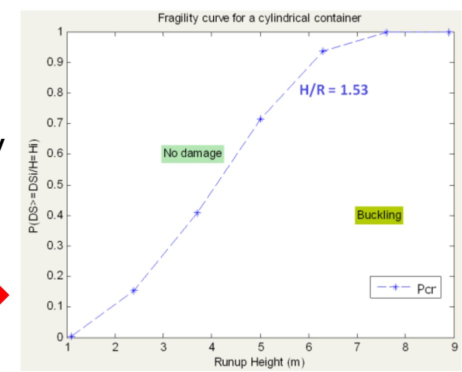
Collapse Mode : shell Buckling

Analytical model developed to predict buckling



Model
$P_{cr} = 0.92E(t/r)^2 / \omega$ $\omega = l / \sqrt{rt}$

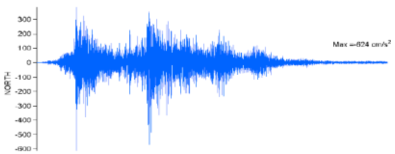
Fragility curve

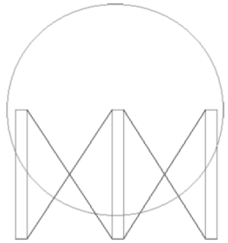


Mechanical models

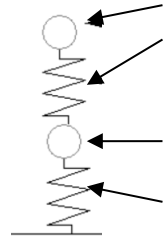
- Earthquake

Analytical models : LPG tanks / cylindrical Storage tanks

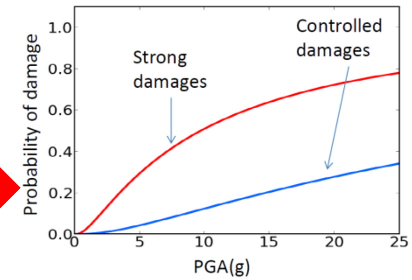




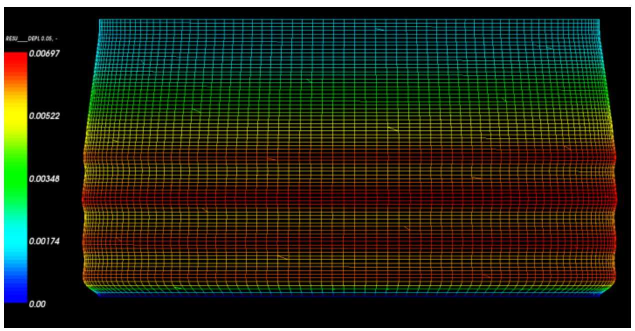
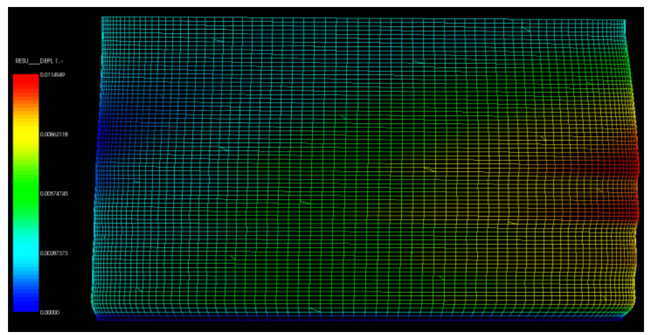
Equivalent models impemented



Fragility curve



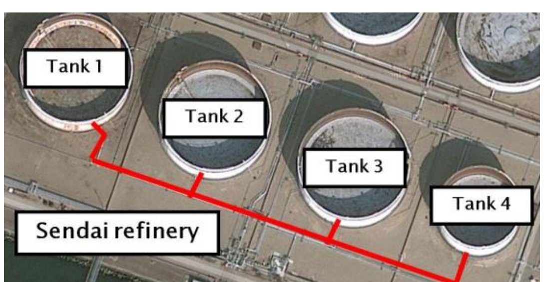
FEM models : Cylindrical Storage tanks and pipelines

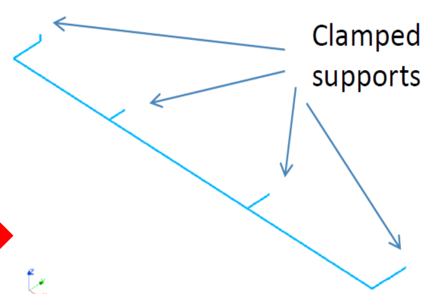
Pushover Model implemented with CODE ASTER (Finite Elements Solver)

Fragility curves still in construction (will be compared with results from analytical analysis)

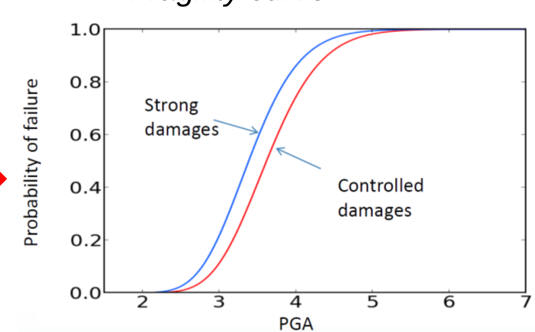
FEM models : Cylindrical Storage tanks and pipelines



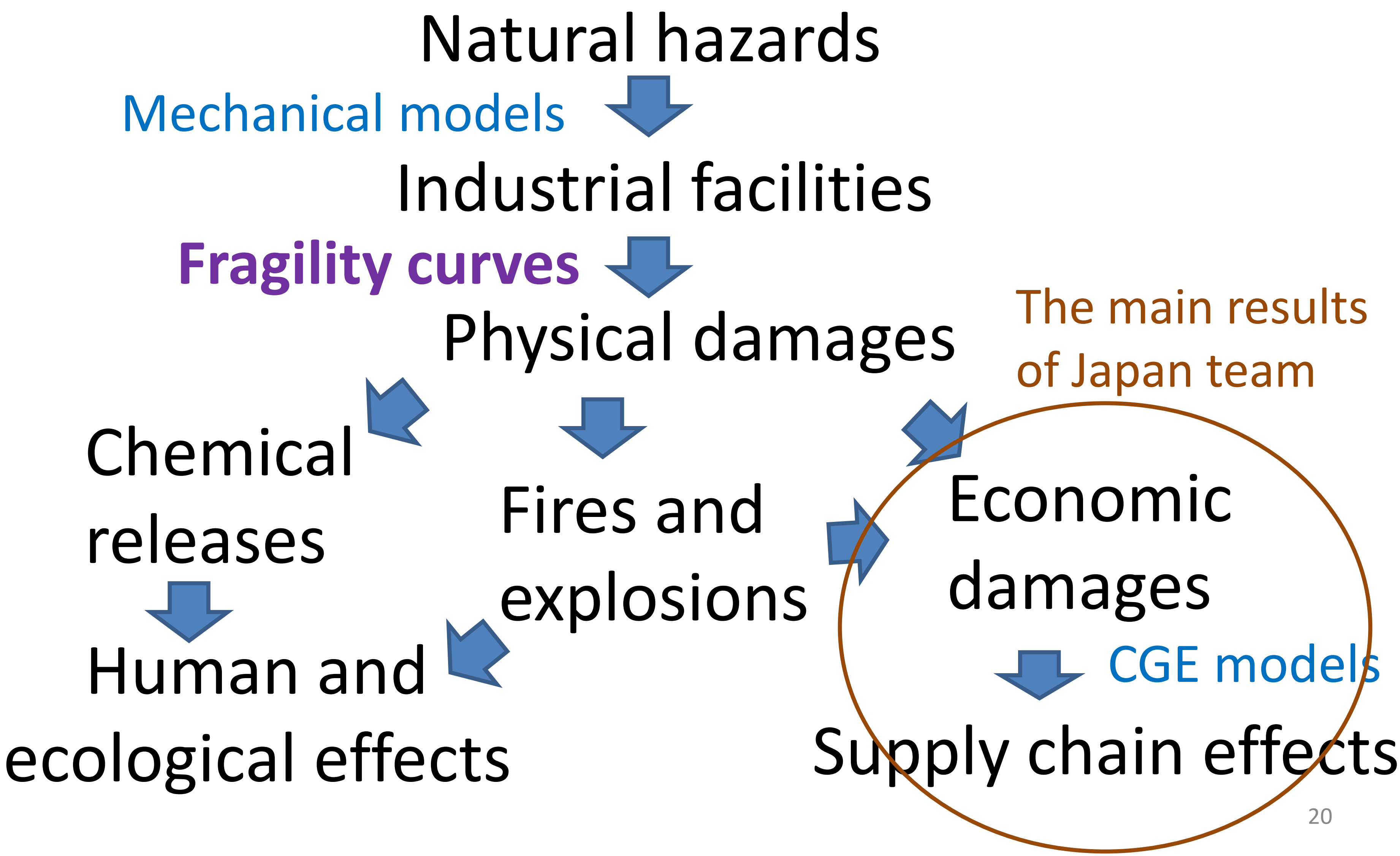
Equivalent models impemented with CODE ASTER



Fragility curve

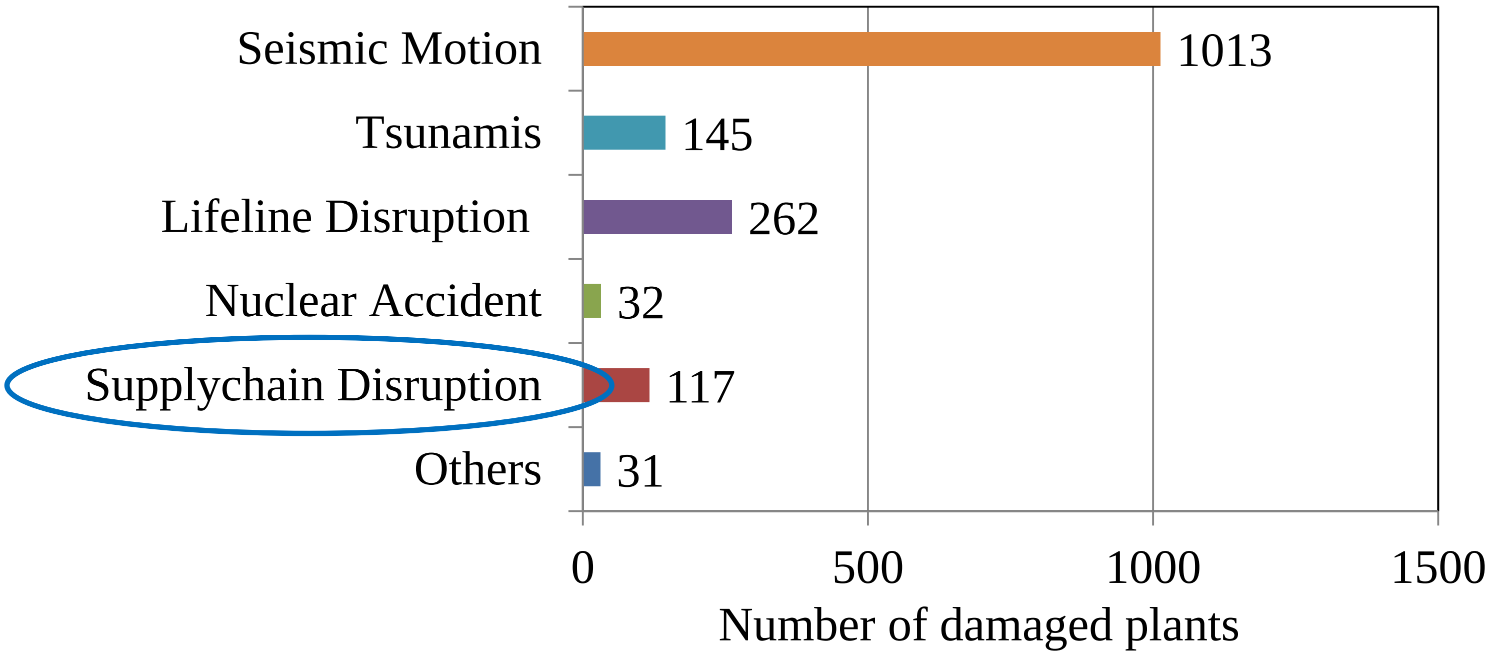


(Extended) Natech risk analysis framework



Supply chain disruption is one of the causes of production stoppage.

- Undamaged firms in unaffected areas were forced to shut down production and lost profit opportunities owing to a lack of parts due to the supply chain disruption caused by the 3.11 Tohoku Earthquake.



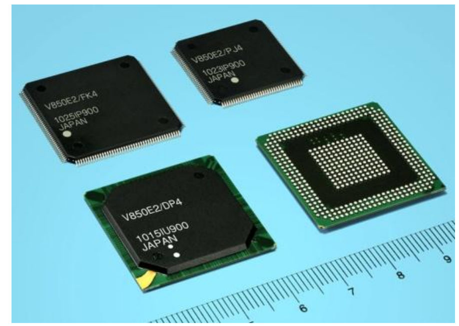
Chujo.J, T.Fujii, M.Nagasawa, and Y.Yoshihumi (2012) "Survey of manufacturing companies damaged by the Great East Japan Earthquake and the effect of transport disruption" (in Japanese) Available at: http://www.kcsweb.co.jp/common/pdf/2012-0601.pdf

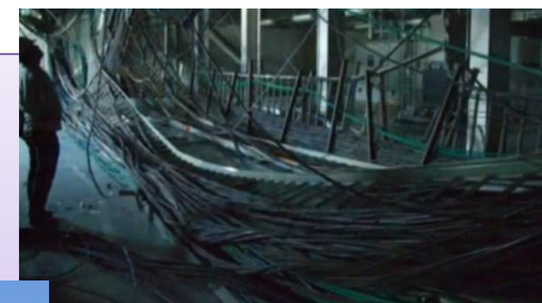
A case of auto industry

The Lack of Critical Auto Parts

Renesas Electronics
Naka Factory

Microcontrollers



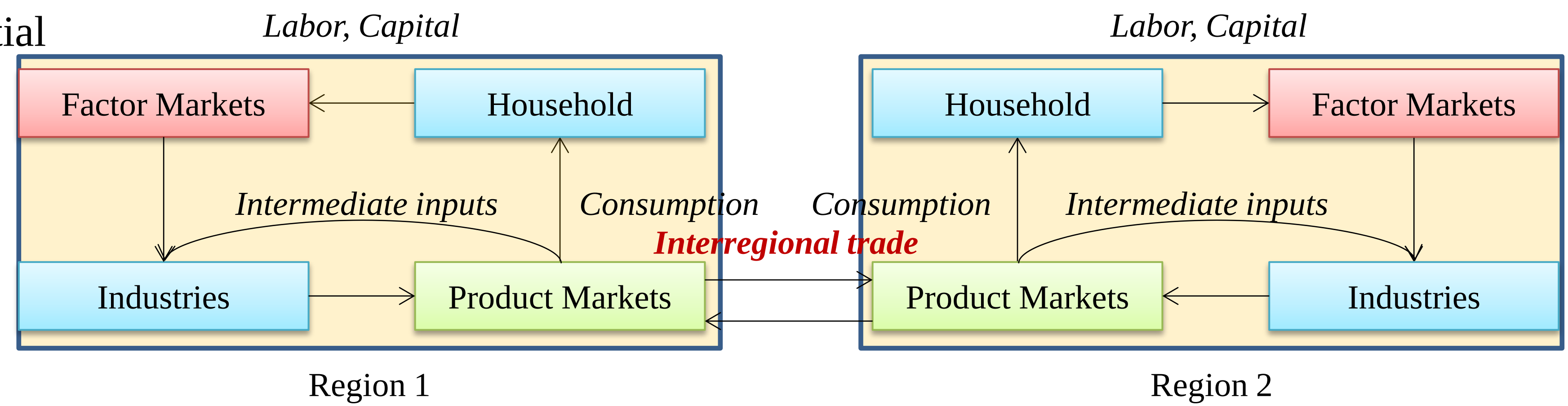


Renesas - Recovery
http://www.youtube.com/watch?v=Vwkdf7j65IQ&feature=related

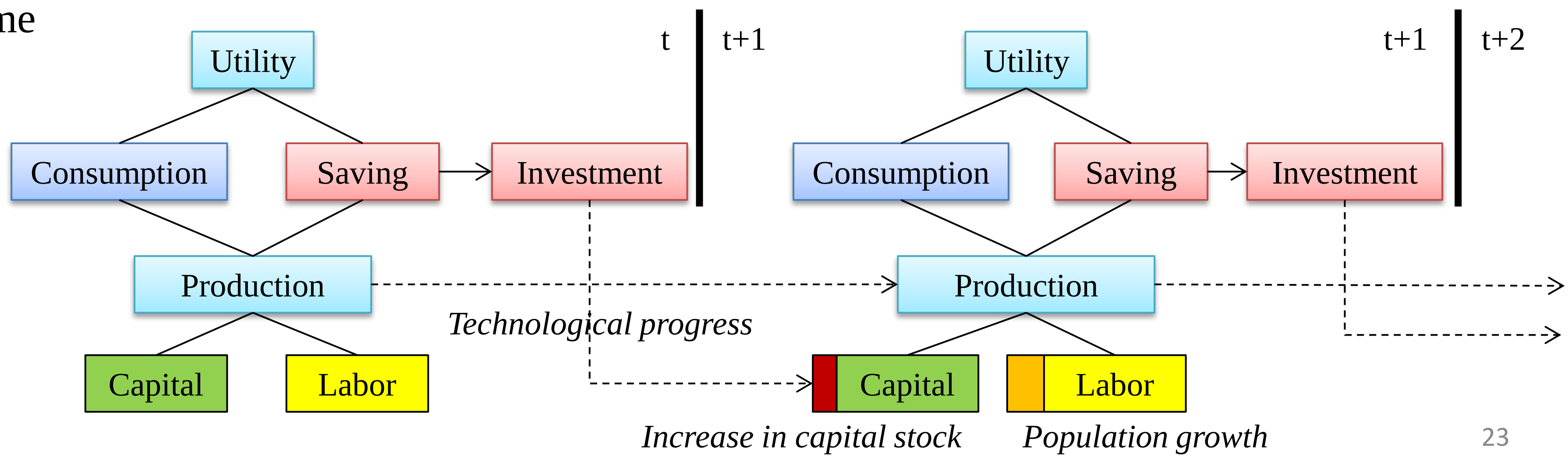
How can the indirect damage be evaluated?

- A Computable General Equilibrium (CGE) model is a comprehensive economy-wide simulation model based on microeconomic theory and an existing input-output table.

Spatial



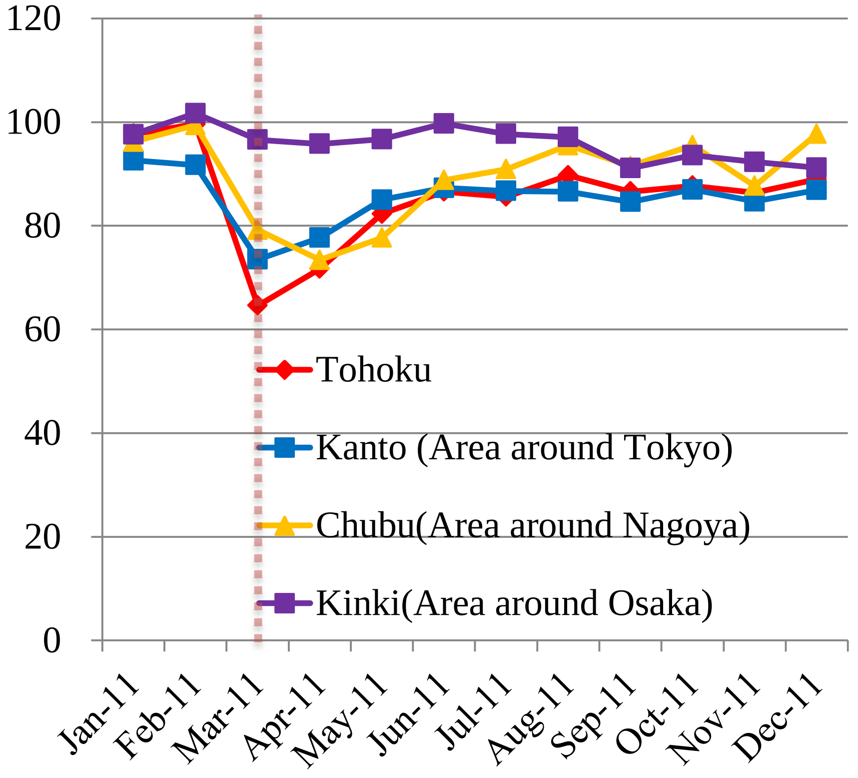
Time



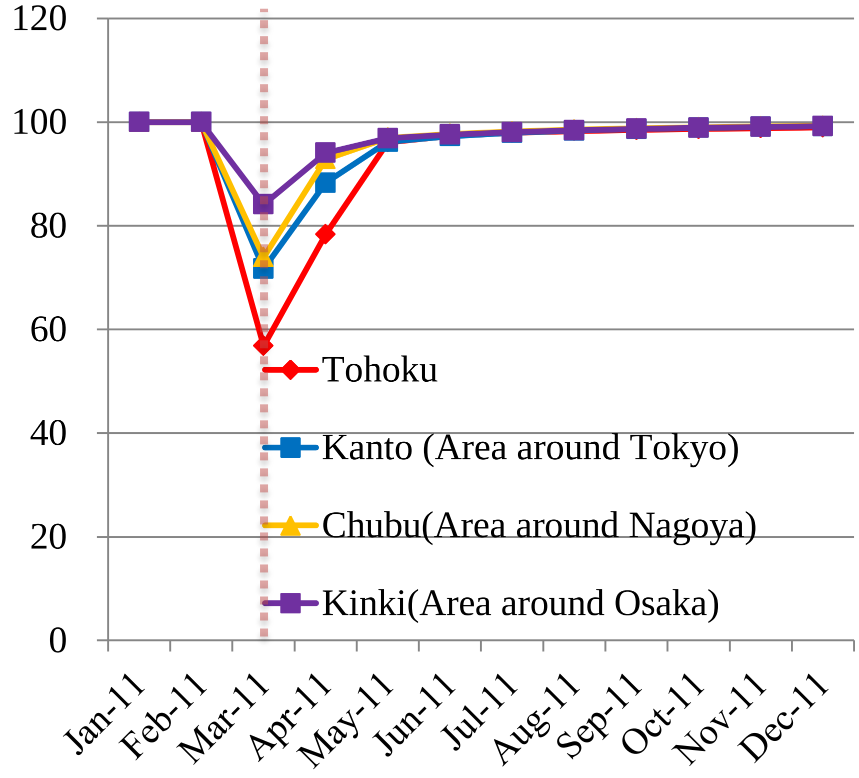
Comparison with Actual Data

- We compared the simulation results for industrial production with the actual data.
- The following results are still preliminary. We need to further research on the modeling.

Actual data: Index of Industrial Production



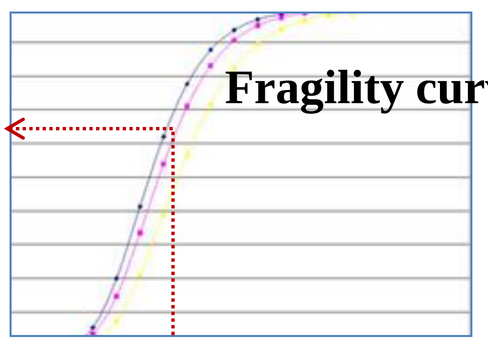
Model Simulation



Ongoing works

- Damage to industrial production can be classified into "direct damage" and "indirect damage".
- The CGE model for a natural disaster can input "direct damage" to estimate total damage to production.
- It is necessary to use the fragility curves to estimate "direct damage to production".

Damage to Industrial Facilities

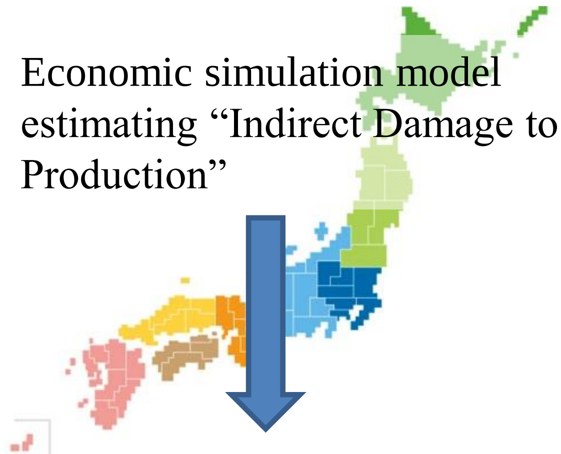


Fragility curves → Input

e.g. Spectral Intensity

Conversion of "direct damage" to "indirect damage to production" applying fragility curves

Economic simulation model estimating "Indirect Damage to Production"



Output : Total Damage to Production

✓Production level of each sector

✓Loss in GDP, GRP etc.

Contributions

- The 3.11 Earthquake was diagnosed as a Natech (Natural-hazard triggered technological accidents).
- The concept of Natech is important because it is one of the emerging risks.
- We must prepare for the next Natech applying both engineering and policy approaches.
- Interdisciplinary approach is needed.
- We must disseminate the concept of Natech in Japan.

Thank you

France team

INERIS

controlling risks
for sustainable development

MSME

Laboratoire Modélisation
et Simulation Multi Echelle

UNIVERSITÉ PARIS-EST

PHIMECA

Japan team

独立行政法人産業技術総合研究所 AIST

RSS 安全科学研究部門

The Disaster Mitigation Research Center of Nagoya University

名古屋大学