KOCAELİ SANAYİ ODASI

PROSES EMNİYETİ SEMPOZYUMU

OMEGA-RISK

DEPREM BÖLGELERİNDEKİ ENDÜSTRİ TESİSLERİNİN RİSK ANALİZLERİNDE DOMİNO ETKİSİ - ADIM ADIM HESAP YÖNTEMİ

Risk Assessment of Industrial Facilities in Seismic Regions Considering Domino Effects – Step by Step Analysis Methods

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Presentation Outline

Objectives

Process and Natural Hazards at Storage Tank Terminals

Risk Calculation Approach

Random Variables for Risk Study

Examples - Hazard Consequence and Individual Risk

Domino Effects

Conclusions

Objectives

Risk assessment for a hydrocarbon industrial facilities requires due consideration of process and non-process hazards;

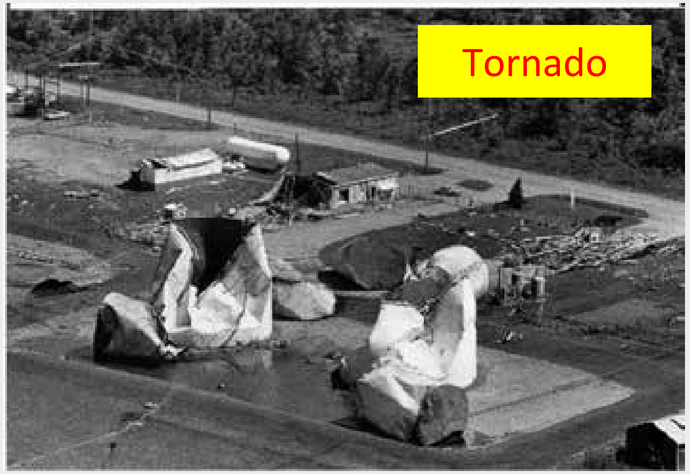
To date, there is no a comprehensive approach, or a set of industry guidelines, or technical publications available that address the risks from hazards such as fire, blast, toxic smoke, tornado, lightening, earthquake, loss of containment (dike failure, etc.), forest fires and etc.;

A significant gap in the industry that lacks to combine the knowledge of process safety, advanced structural analysis, and reliability together to accurately and reliably estimate the individual, environmental and facility damage risks from such hazards.

Lastly, there is a considerable need for inclusion of domino (knock-on) effects in the analysis whereby multiple failures and catastrophic events are initiated simultaneously or in very close proximity to each other.

Conclusion: there is a need for a comprehensive, holistic approach for determining risk in and around the hydrocarbon storage tank terminal accounting for domino effects.

Potential Process and Non-Process Hazards



Potential Process and Non-Process Hazards

PRIMARY EVENTS

Process Hazards
- Fire (pool fire, rim fire, pontoon fire, seal fire, tank surface fire, jet fire)
- Vapor Cloud Explosion
- Toxic

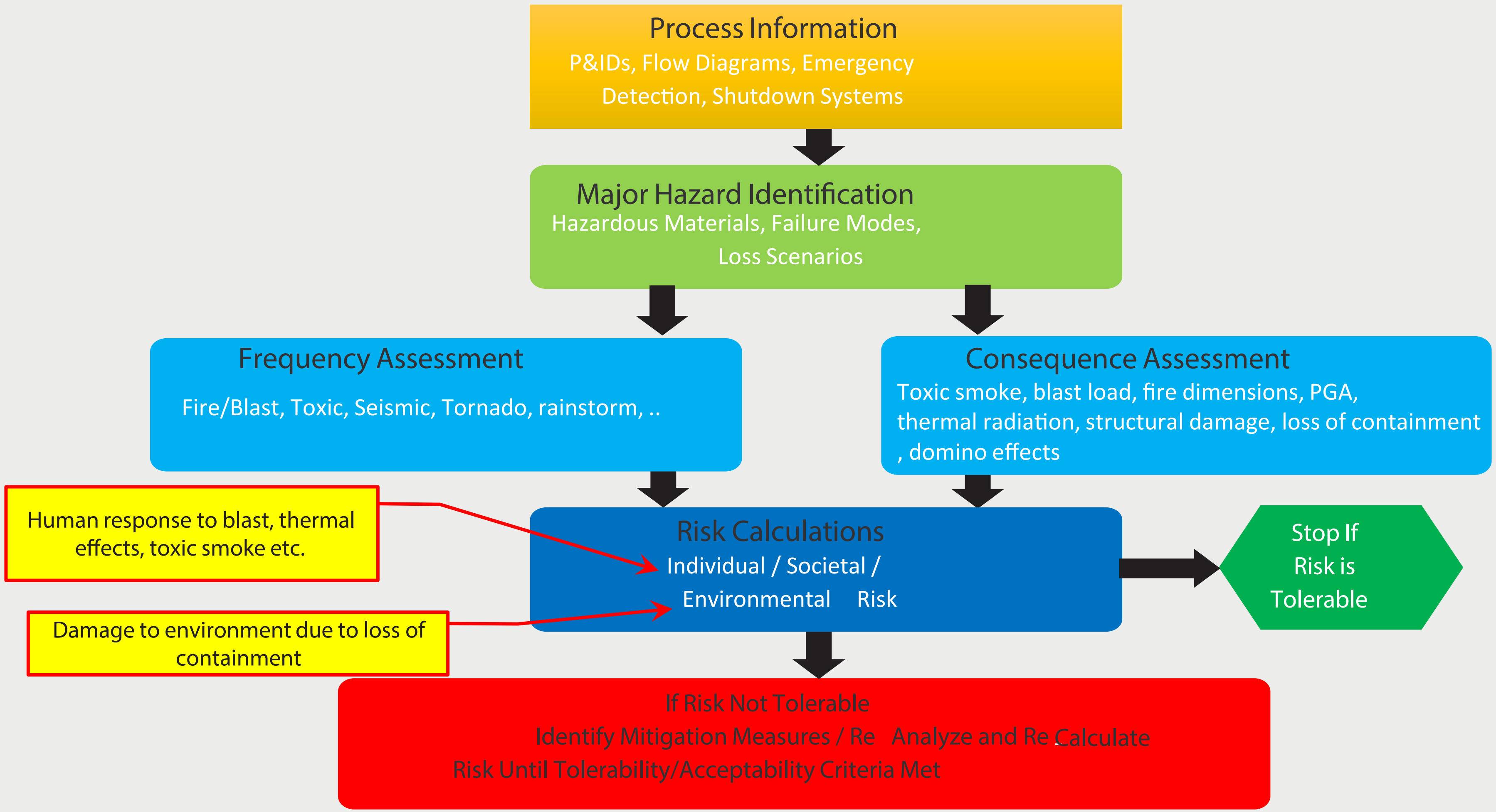
Natural Hazards
- Lightning
- Seismic Event
- Tornado
- Flooding/Rainstorm/Hurricane

Man – Made Hazards
- Terrorist Attack
- Fire – Fighting Activities*

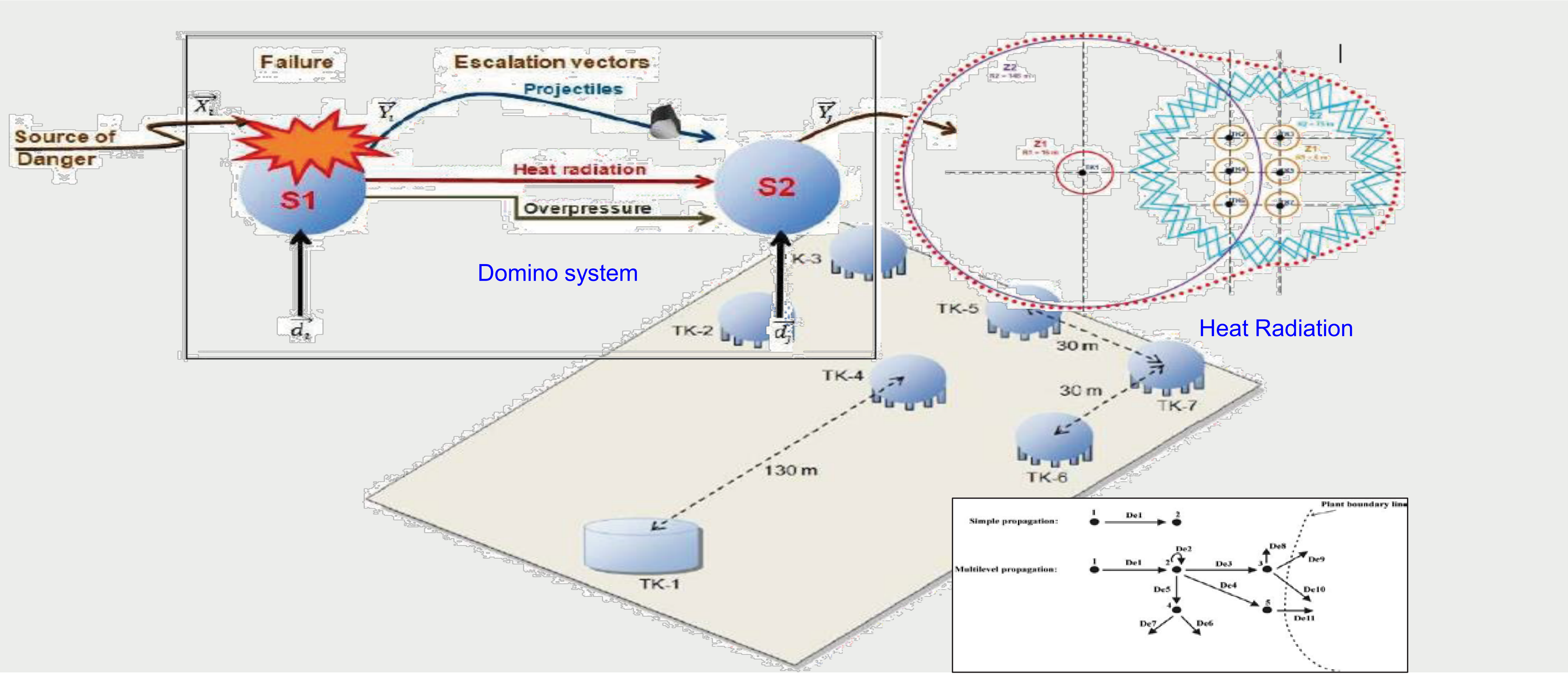
ESCALATIONS
(Secondary, Tertiary .. Events)

- Boil-over
- Dyke (Bund) Fire
- Surface Fire
- Toxic Smoke
- Loss of Containment
- Forest Fire
- Explosion

Risk Assessment Flow Diagram



Domino Effects



A Dike Fire that leads to Tank Full Surface Fires and Boil-Over- illustration

(1) Secondary containment area fire:

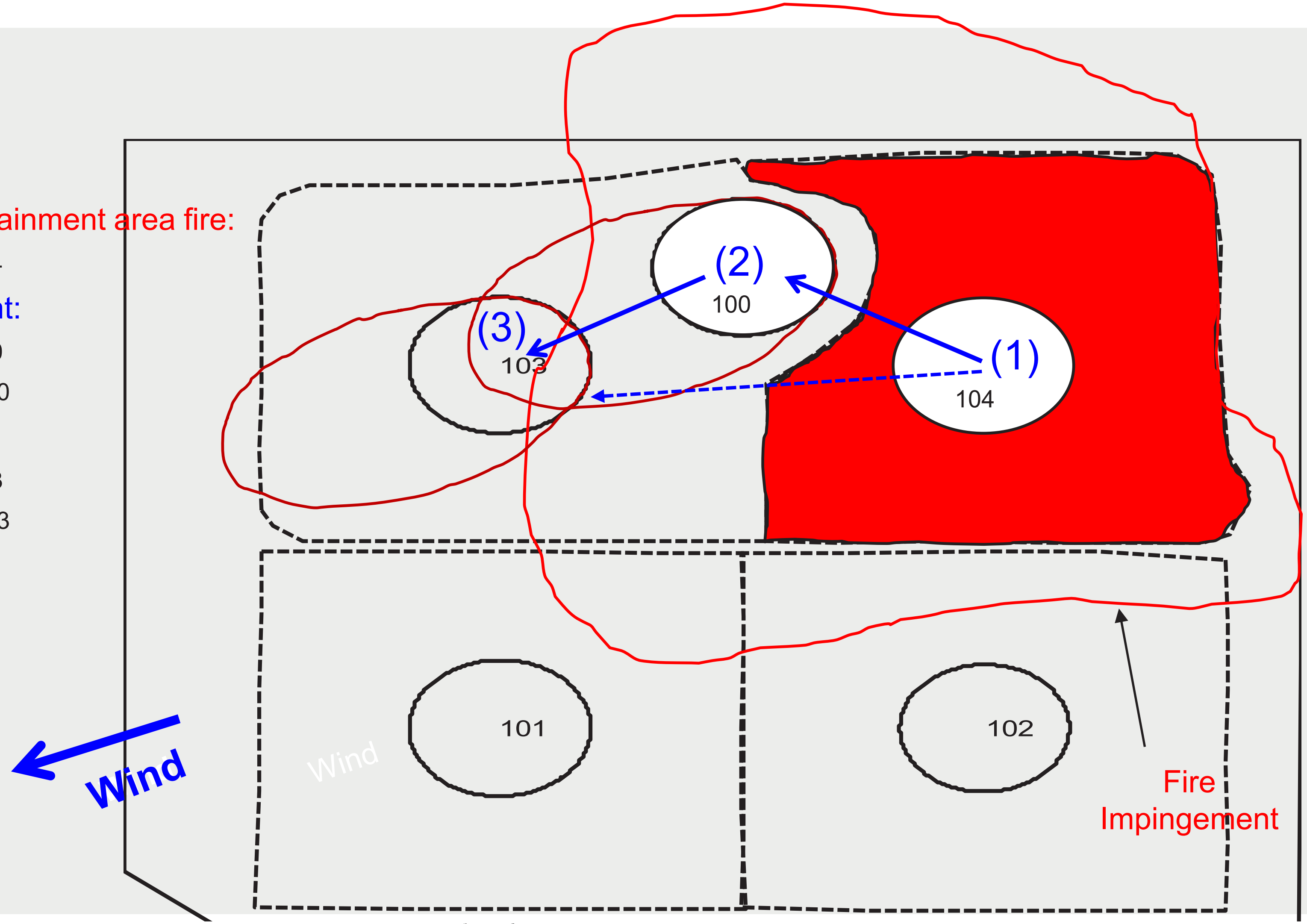
- Dike fire at Tank 104

(2) Secondary event:

- Pool fire at Tank 100
- Boil-over at Tank 100

(3) Tertiary event:

- Pool fire at Tank 103
- Boil-over at Tank 103



A Dike Fire that leads to Tank Full Surface Fires and Boil-Over- illustration

(1) Primary event:

- Dike fire at Tank 104

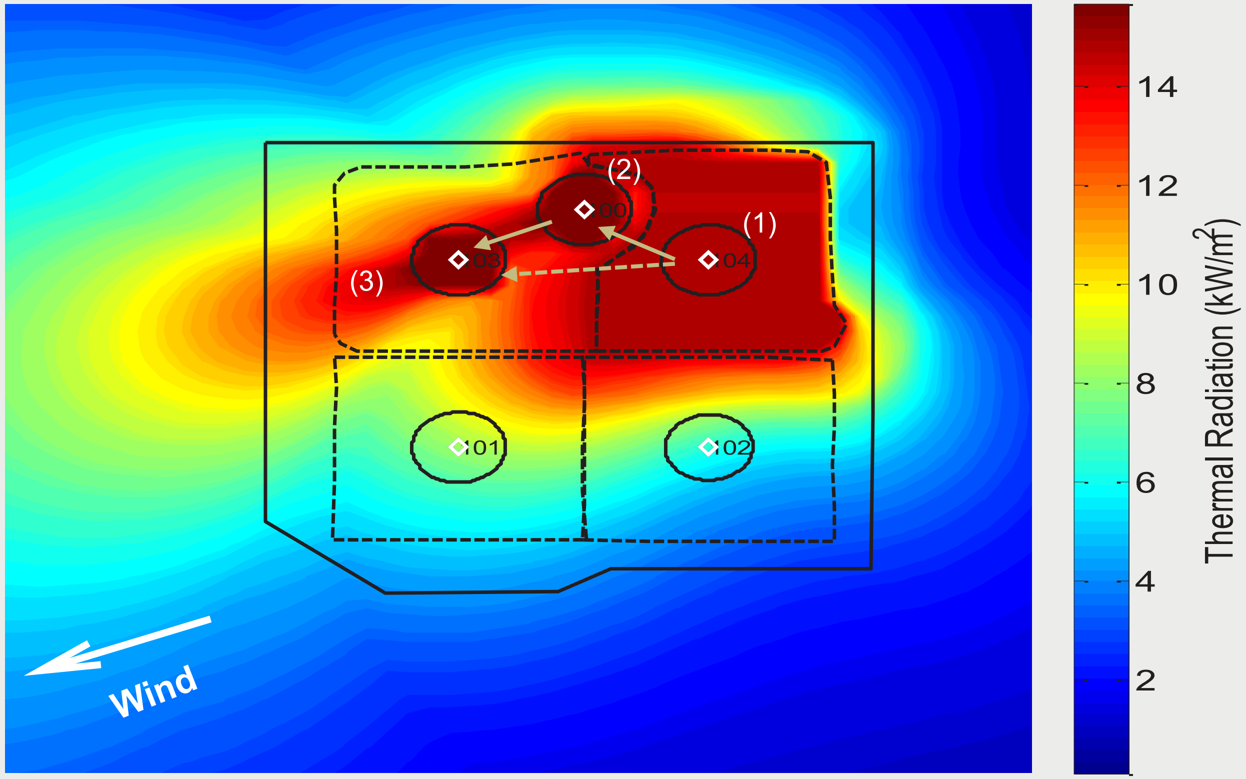
(2) Secondary event:

- Pool fire at Tank 100
- Boil-over at Tank 100

(3) Secondary event:

- Pool fire at Tank 103
- Boil-over at Tank 103

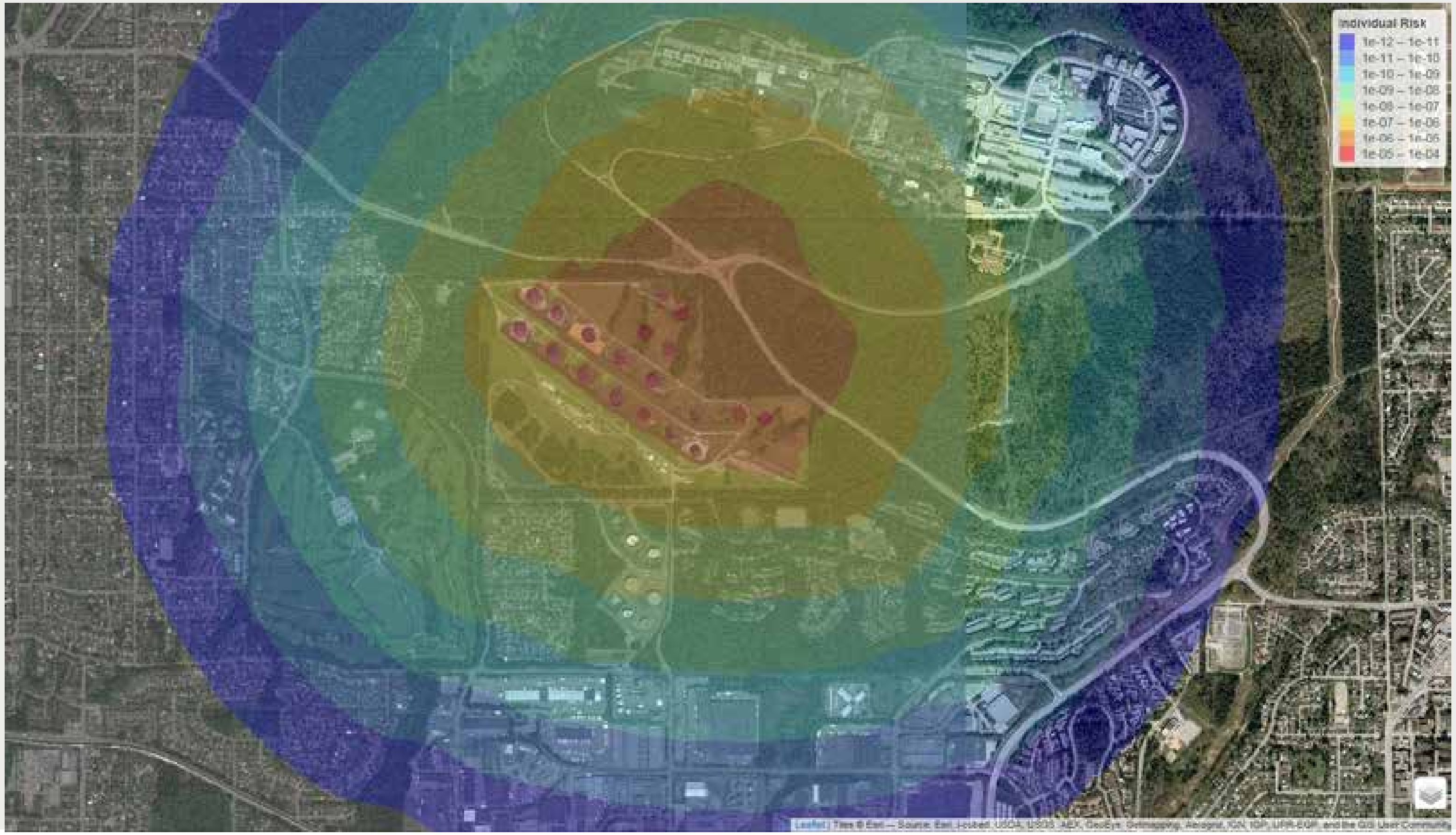
Wind



Individual Risk Contours with Domino Effects

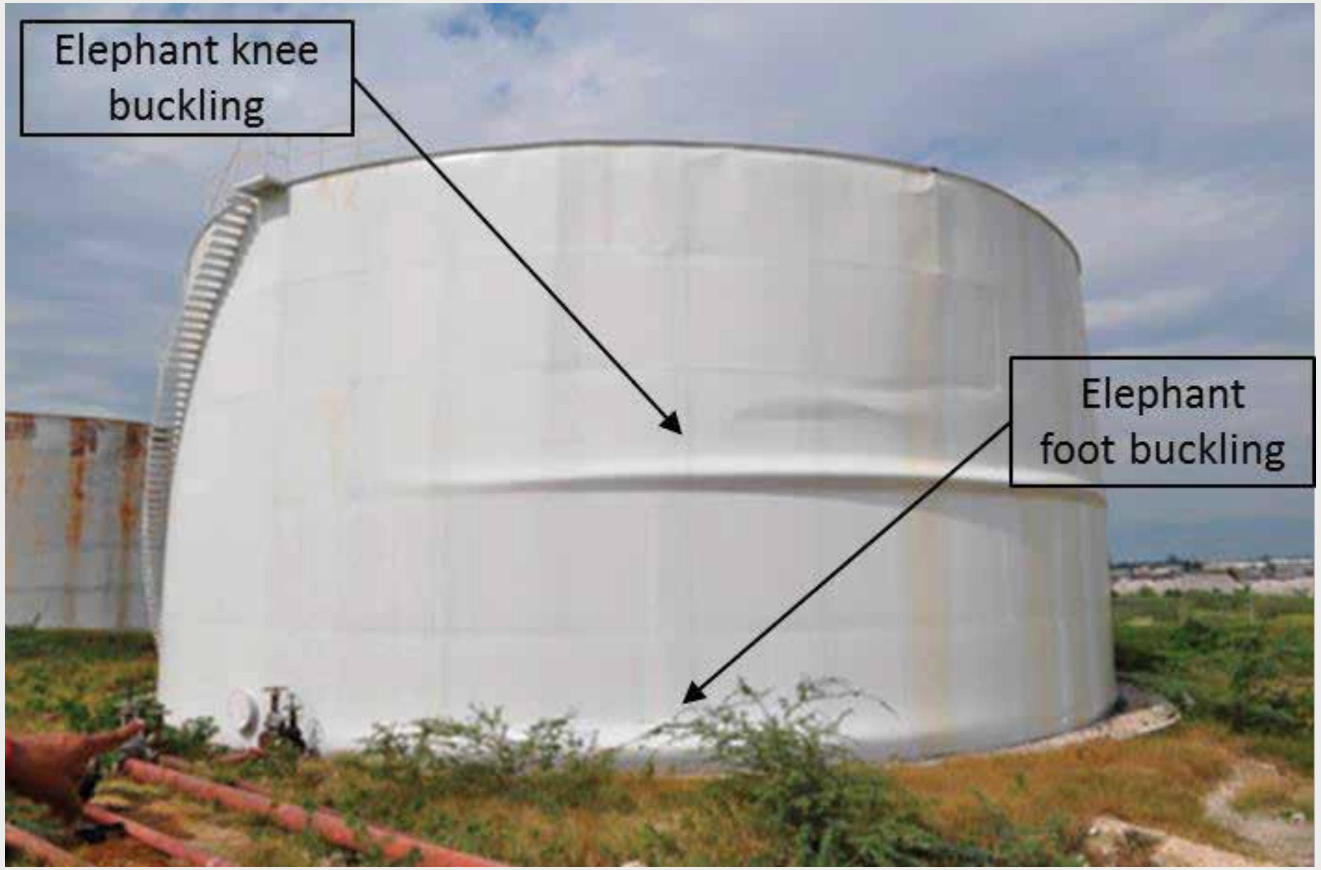
Red color indicates 1.0E-04; Blue color: 1.0E-12

University and Residence: 1.0E-06 - 1.0E-05



Seismic Response of Storage Tanks

- “Elephant's foot" and "elephant knee" buckles



Tank with "elephant's foot" and "elephant knee" buckles from Haiti 7.0 earthquake in 2010

Seismic Response of Storage Tanks

- “Elephant's foot" buckles

Fluid-filled tank buckled in "elephant-foot" mode during Northridge earthquake in California

Elephant’s foot buckle at the base of a storage tank during 1964 earthquake in Alaska

Seismic Response of Storage Tanks

- Shell buckling due to sloshing

Sloshing damage to upper shell of tank during 1971 earthquake in California

Sloshing damage to upper shell and roof of tank during 1999 earthquake in Turkey

Seismic Response of Storage Tanks

- Rupture of weld/bolt connections

Fracture of tank anchors during 1995 earthquake in Japan

Lengthening the anchor rod, deformation of tank (5000 m^3 oil), and concrete cracking during 2001 earthquake in Peru

Seismic Response of Storage Tanks

- Pipeline separation, elephant foot buckling, and sloshing buckling at the same tank in an earthquake

Same Tank

Water sloshing lifted this tank off the ground causing pipeline separation and elephant foot failure during 1992 Landers earthquake in San Diego.

Damage at the top of the tank where water in the tank pushed up on the roof during 1992 Landers earthquake in San Diego

Seismic Response of Storage Tanks

- Failure of concrete piles

Failure of concrete piles supporting Liquid oxygen tanks during the 1999 Izmit earthquake in Turkey

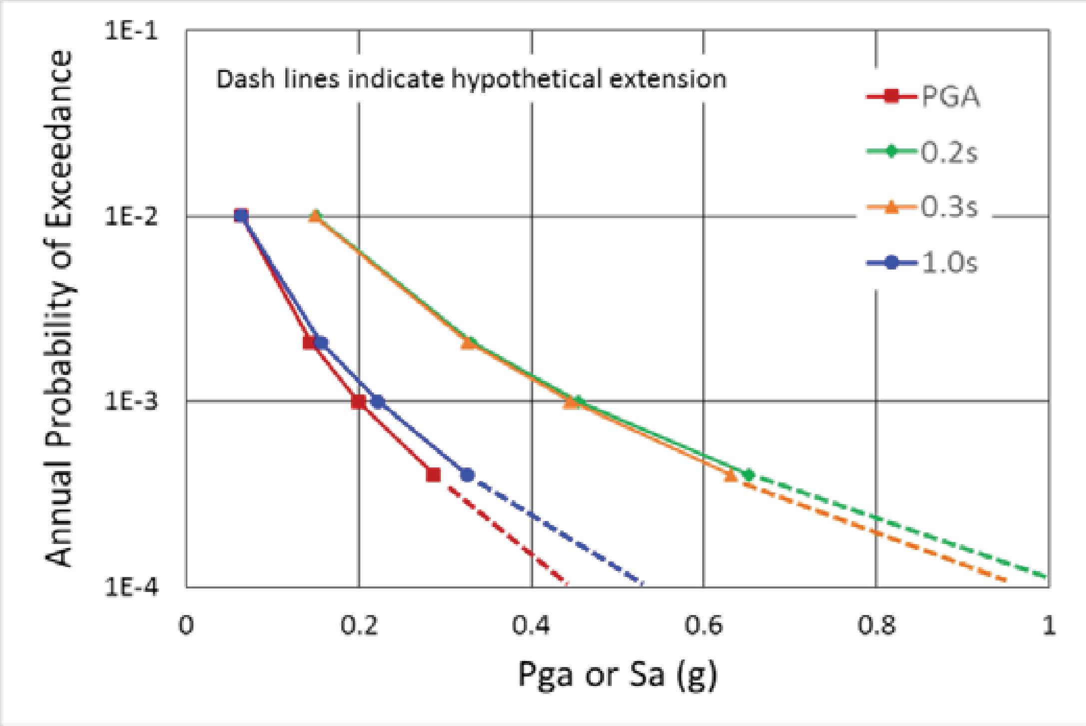
Seismic Hazard

- Seismic hazard is among the most natural threats to storage tanks. A seismic event can lead to subsequent events (escalation) such as fire and explosion

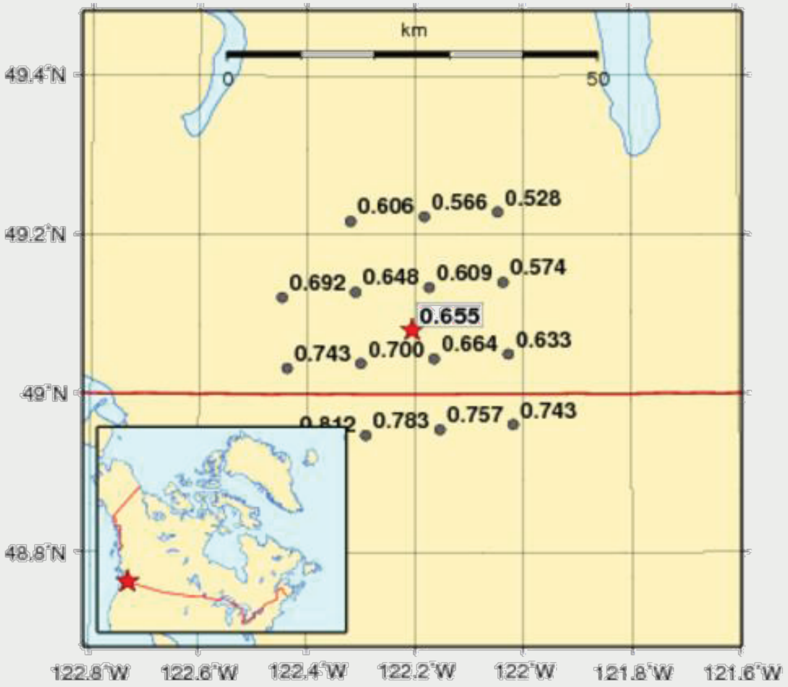
Tank farm fires after Kocaeli Earthquake (1999) in Turkey

Sloshing damage to upper shell and roof of tank during 1999 earthquake in Turkey

Site seismic hazard curves– Exceedance Curve– Step 1

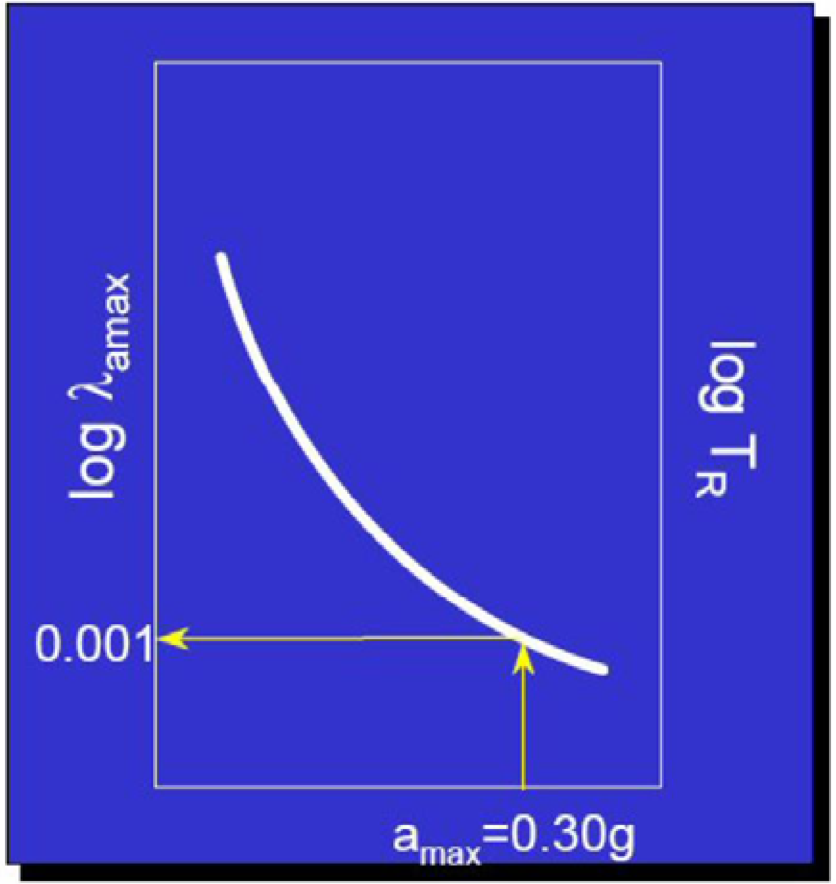


Seismic Frequency of Exceedance Curves for a Site assuming "firm ground" or Soil Class C.



Nearby grid values for Sa(0.2s)

Seismic Hazard Curves



- Probability of exceeding a_{max} = 0.30g in a 50 yr period?

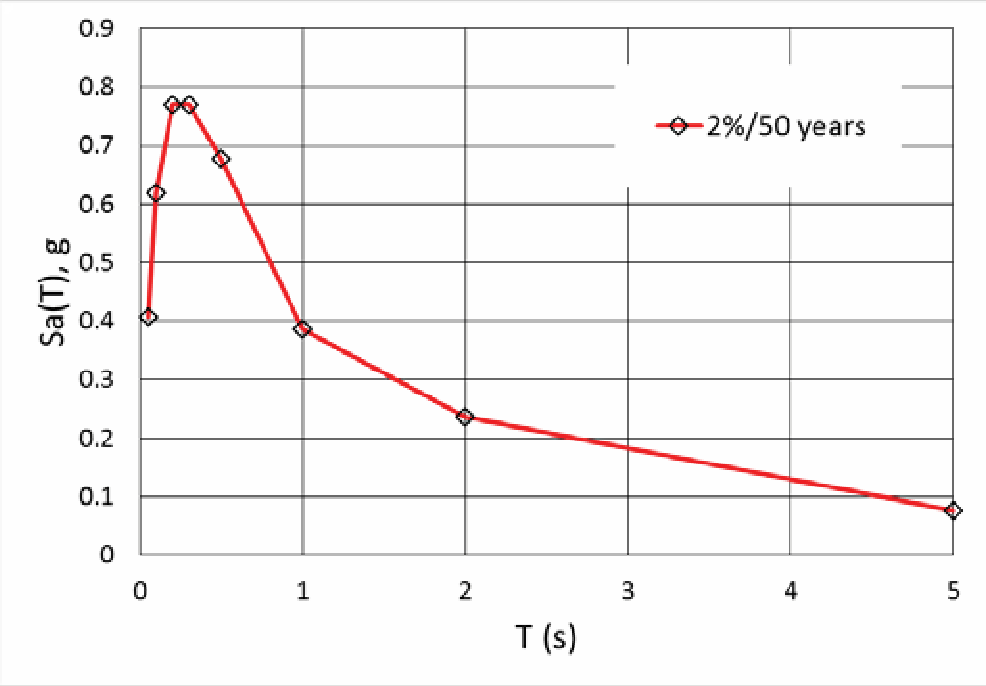
$$p = 1 - e^{-\lambda t}$$
$$= 1 - \exp[-(0.001)(50)]$$
$$= 0.049 = 4.9\%$$

- In 500 yr period?

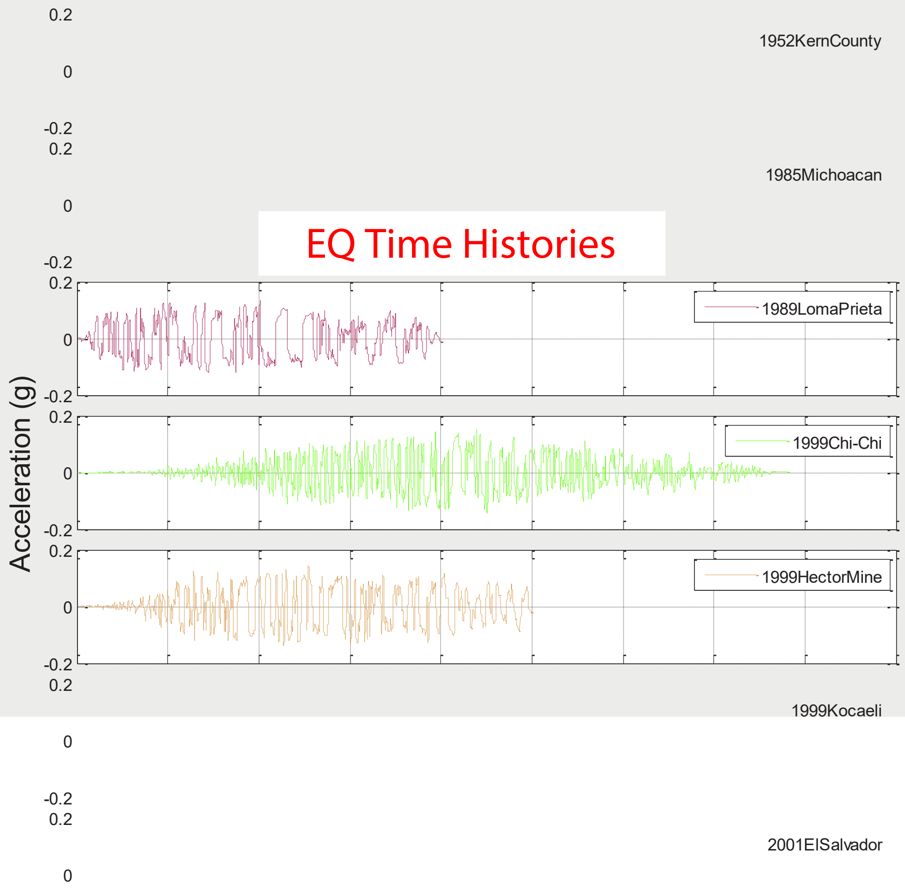
$$p = 0.393$$
$$= 39.3\%$$

Uniform Hazard Spectrum and Time History Scaling Step 2

Seismic Spectrum



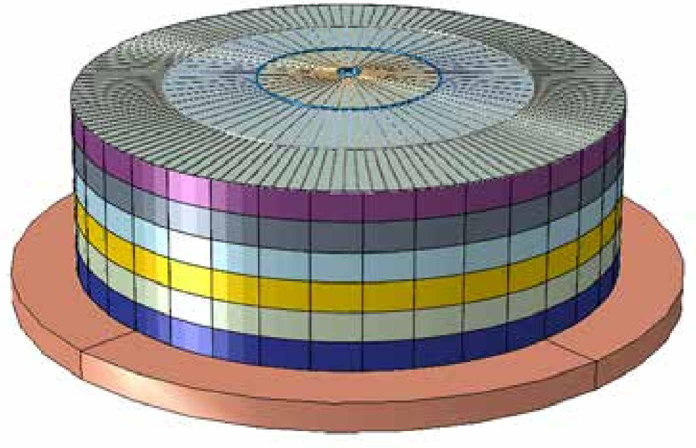
EQ Time Histories

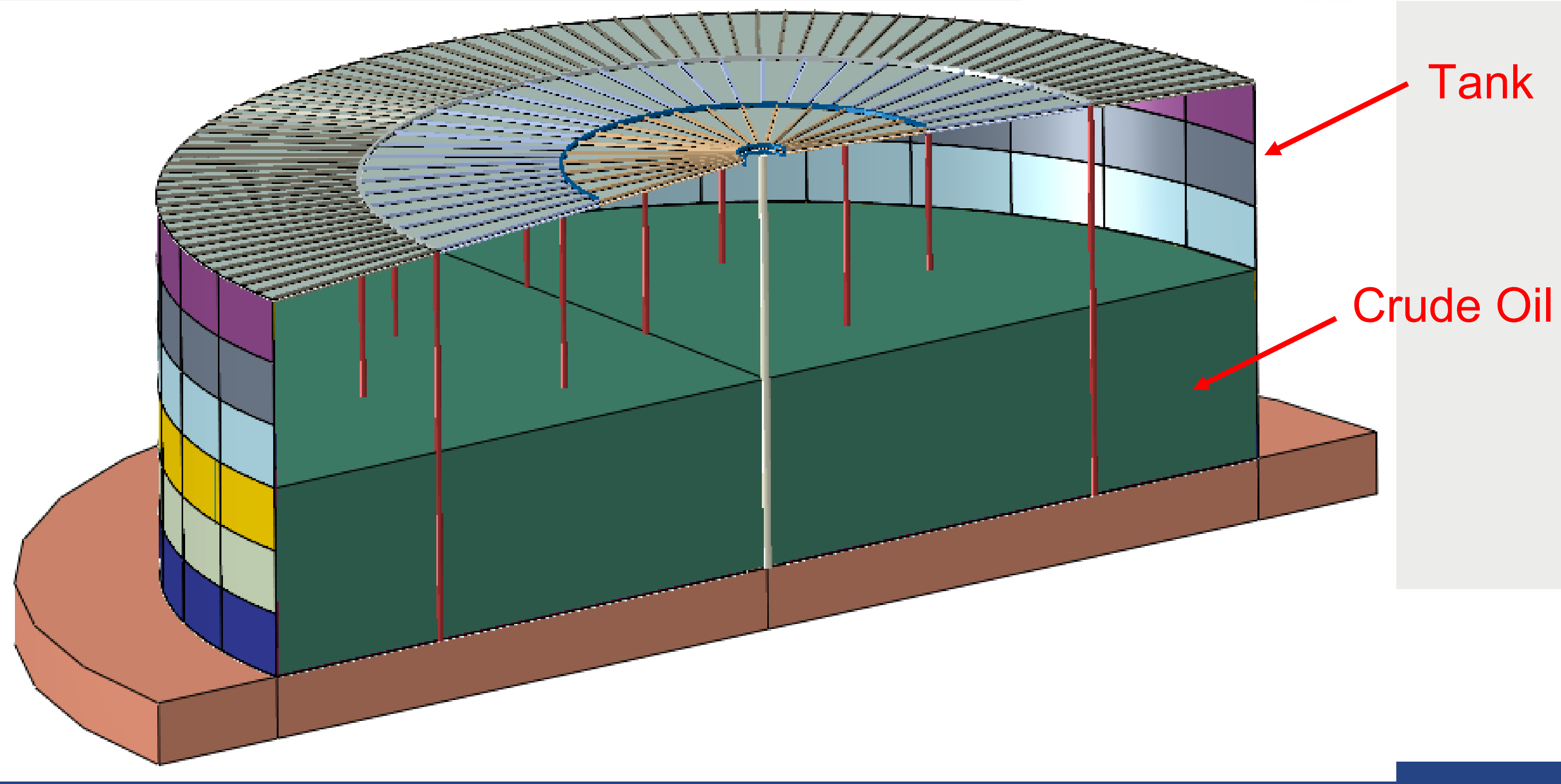


Seismic Response of Tanks, and Damages– Step 3

Finite element model of the tank includes:

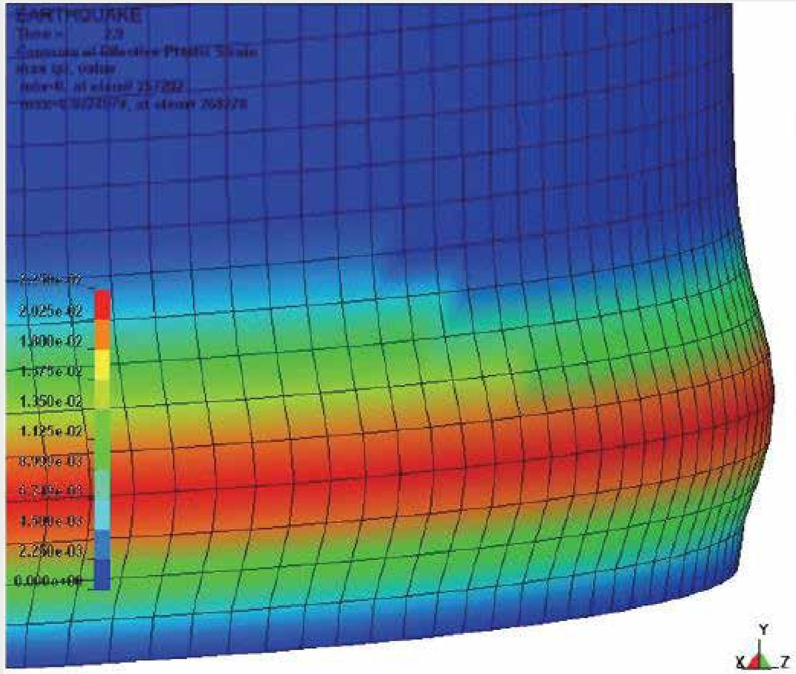
- Tank
- Crude oil inside the tank
- Soil underneath the tank



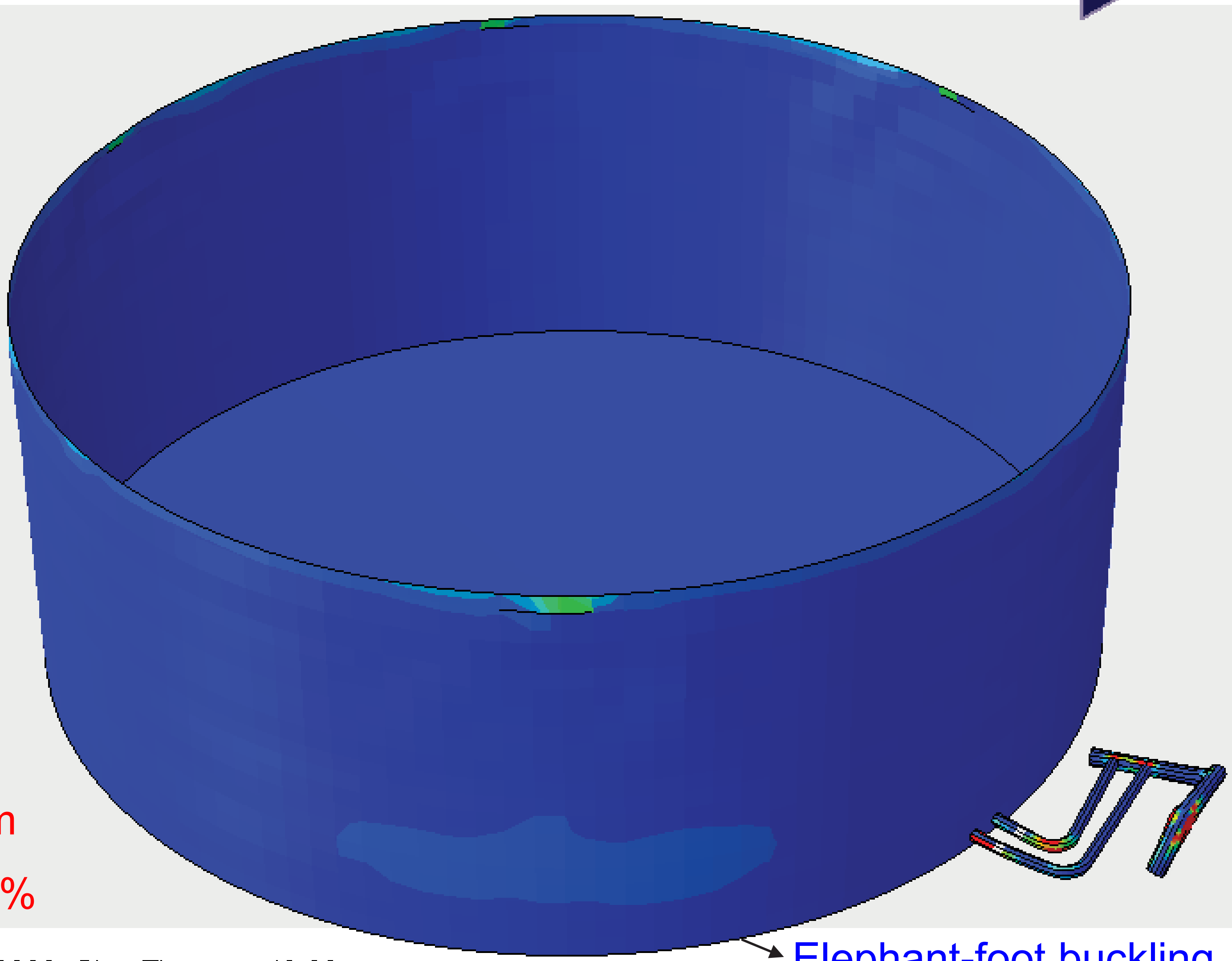


Seismic Response of Tanks, and Damages

- Elephant foot buckling predicted by advanced finite element analysis



Kern County Earthquake– 0.6g



Red color indicates 5% plastic strain Max = 51.4%

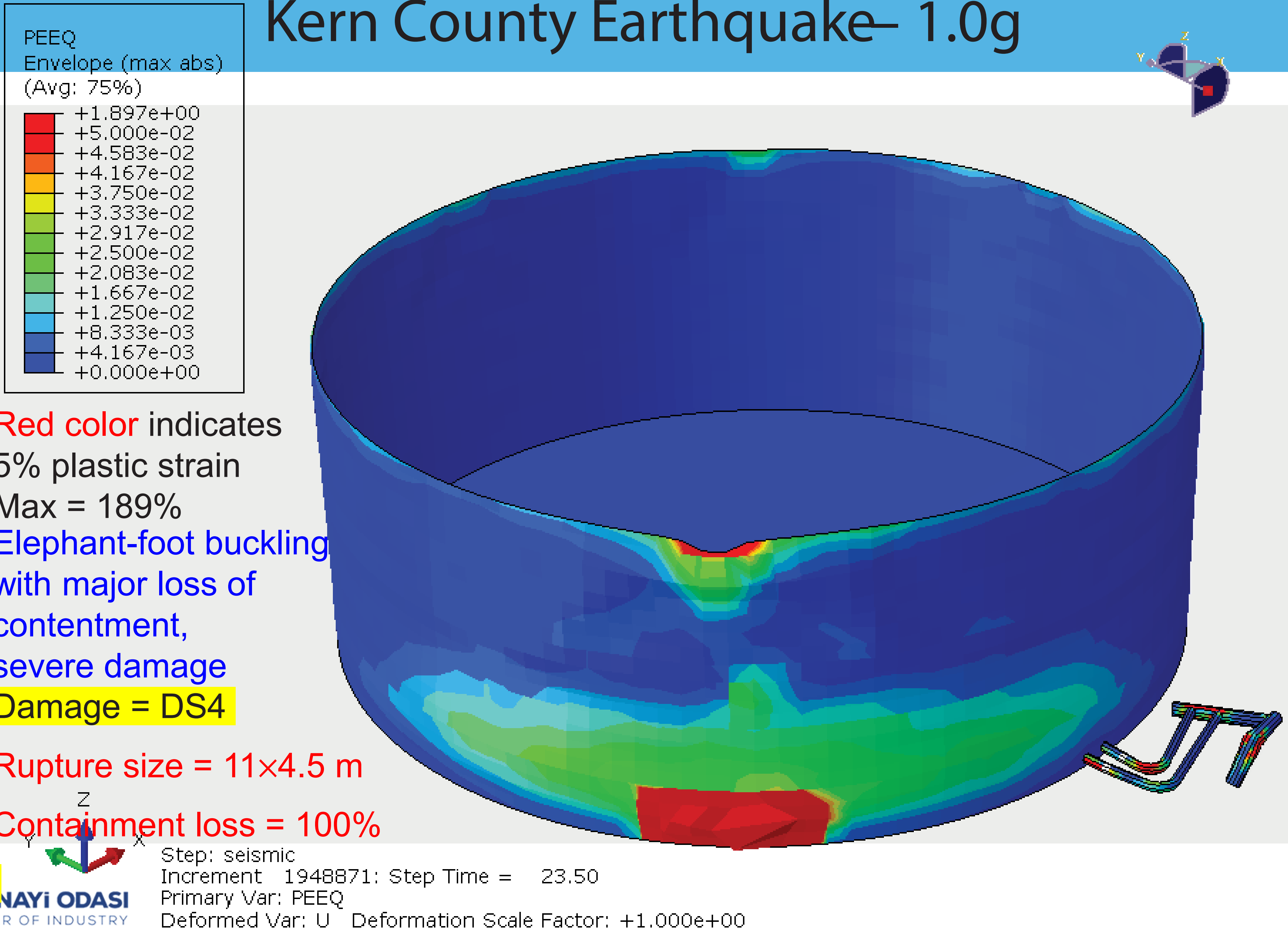
Elephant-foot buckling with minor loss of contentment

Damage = DS3

Rupture size = 5×2.5 m

Containment loss = 50%

Kern County Earthquake– 1.0g



Red color indicates 5% plastic strain
Max = 189%

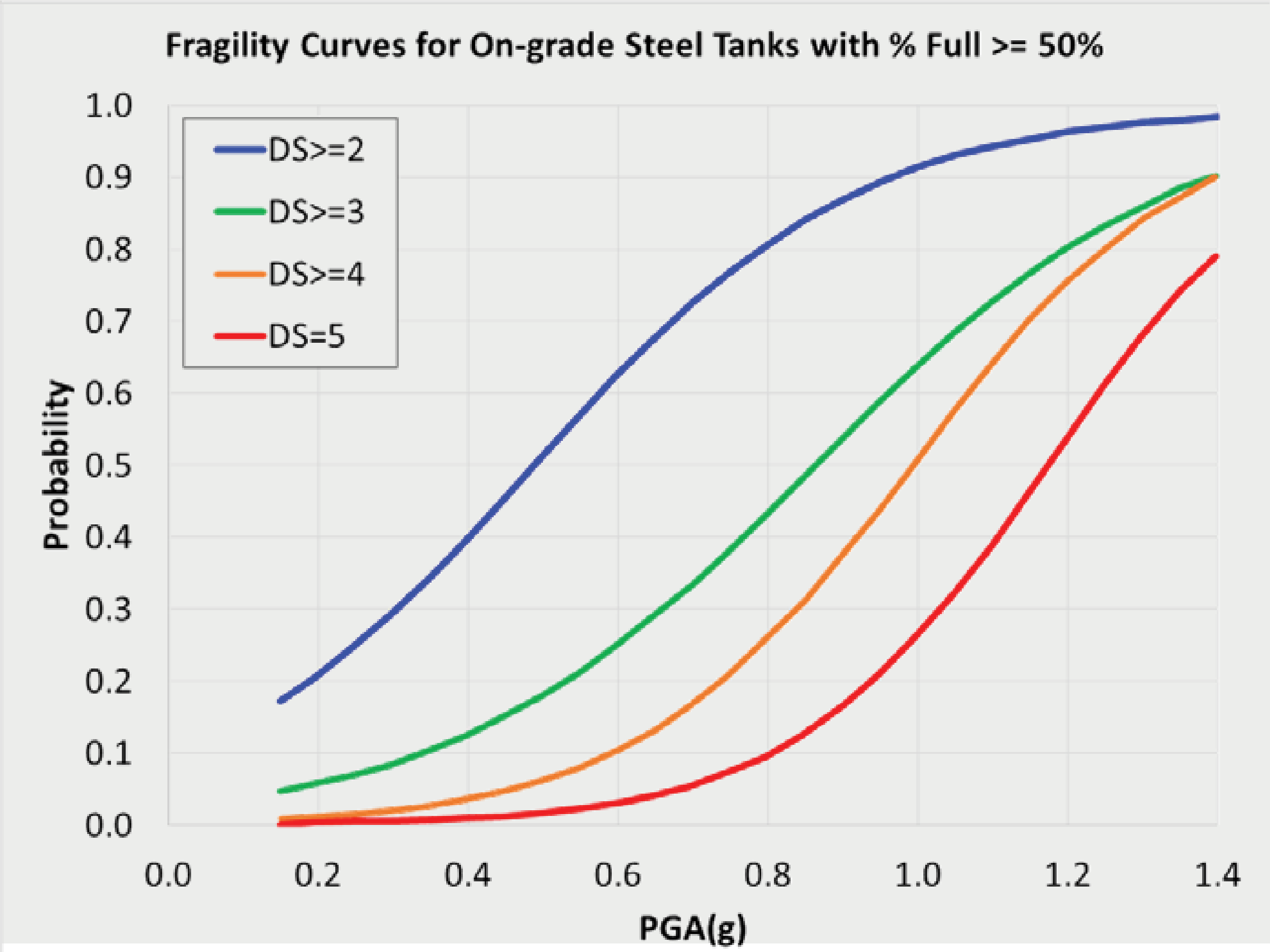
Elephant-foot buckling with major loss of contentment, severe damage

Damage = DS4

Rupture size = 11×4.5 m

Containment loss = 100%

Seismic Fragility Curves for Storage Steel Tanks with % Full > 50 - Step 4



Damage States

DS1	No damage to tank or I/O pipes
DS2	Damage to roof, minor loss of contents, minor damage to piping, but no elephant-foot buckling
DS3	Elephant-foot buckling with minor loss of content
DS4	Elephant-foot buckling with major loss of content, severe damage
DS5	Total failure, tank collapse

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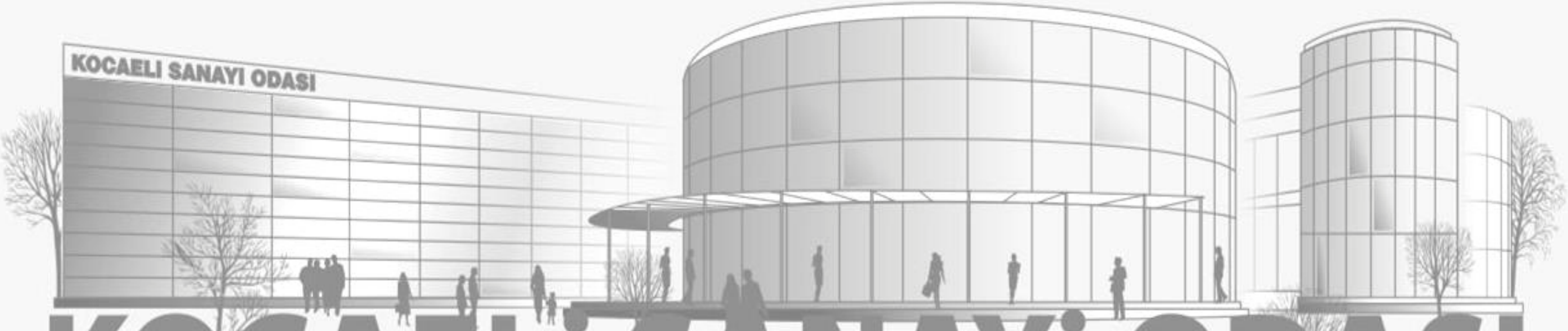

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Risk Calculation Given No Escalation

$$P(FII) = \sum_{i}^{N} P(FI|A_i) \times P(A_i) \times P(I\ at\ A_i)$$

Where,

P(FII) = probability of an individual experiencing a fatal injury (FI);

$P(FI|A_i)$ = probability of an FI occurring given an event (A_i) occurs;

$P(A_i)$ = probability of an accidental event (A_i) occurring;

$P(I\ at\ A_i)$ = probability that an individual is present when an accidental event A_i occurs;

N = number of events in fire, blast, seismic, etc.

The probability of individual present when an accidental event occurs will be estimated based on the working schedules of the personnel on site, for example if an individual works 50 hours a week, this probability can be estimated as 50/(7x24hrs) = 50/168 or 0.30. For the people outside the boundary of the terminals, this probability will be assumed to 100%, i.e. 100% of the time an individual is present given an accidental event occurs.

Risk Calculationwith Escalation

$$P(FII|E) = {}_{i}^{N} P(I|E_i) \times P(A_i) \times P(E_i|A_i) \times P(FI|E)$$

Where,

P(FII|E) = probability of an individual experiencing a fatal injury given an escalation;

$P(I|E_i)$ = probability of an individual present given an escalation occurs;

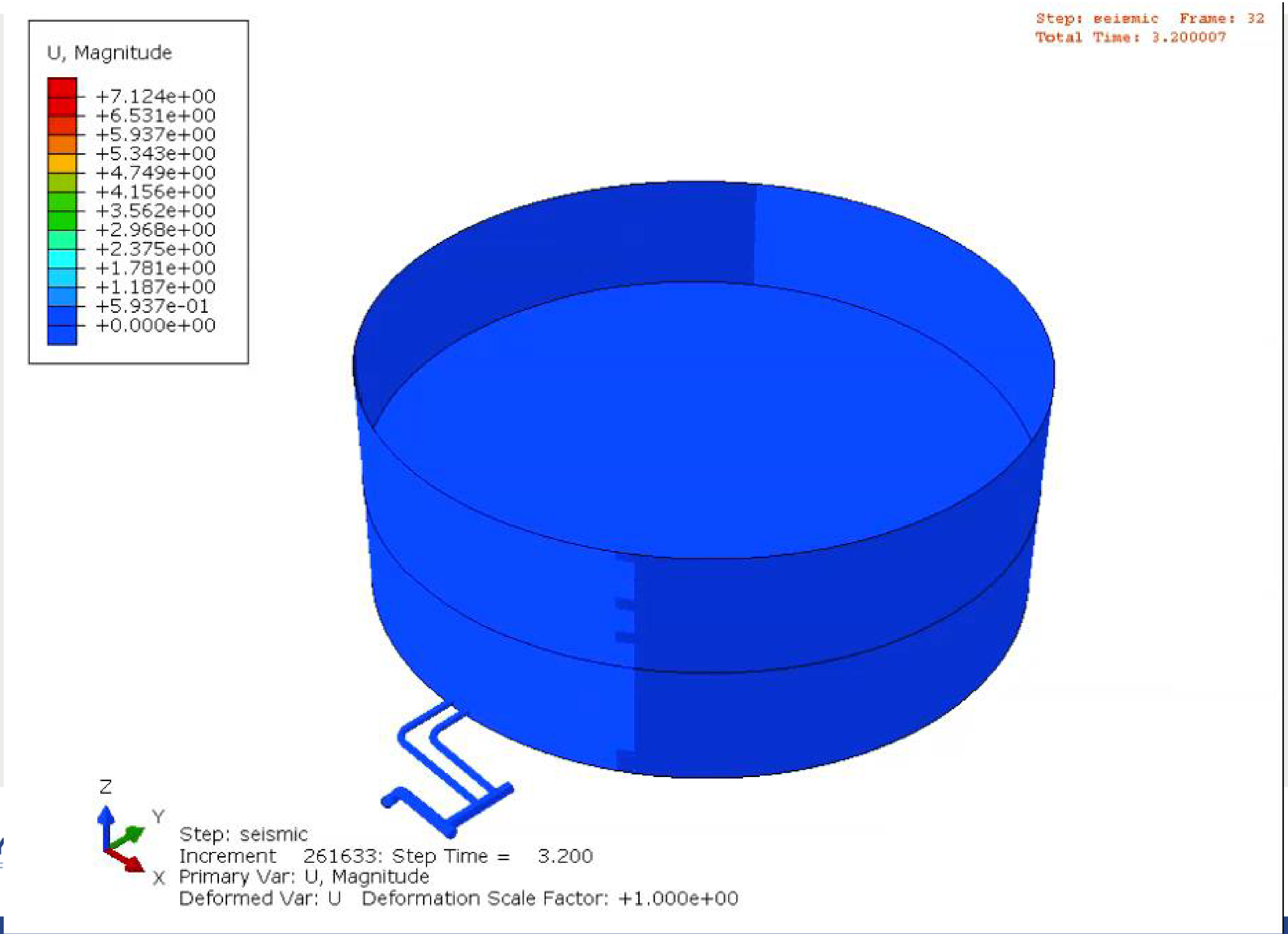
$P(A_i)$ = probability of an accidental event (A_i) occurring;

$P(E_i|A_i)$ = probability of an escalation occurring given an event

P(FI|E) = probability of an FI occurring given an escalation occurs, i.e. human vulnerability at certain escalation level;

N = number of events in fire, blast, seismic, etc.

Seismic Response of Tanks, and Damages



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Seismic Response of Tanks, and Damages