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EVENTI SISMICI: PREVENZIONE, PROTEZIONE, SICUREZZA, EMERGENZA

XVI Incontro LA SICUREZZA DEL LAVORO NEL XXI SECOLO: QUALI PROSPETTIVE? Ricordo del Prof. Ing. Werther Neri

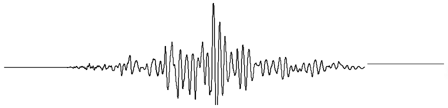
aias dal 1975 networkaias

La Vulnerabilità e Protezione Sismica di Componenti di Impianti Industriali

Fabrizio Paolacci

Università degli Studi Roma Tre

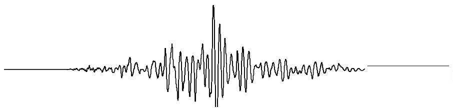
ROMA TRE UNIVERSITÀ DEGLI STUDI



Novembre 17 2016, Bologna

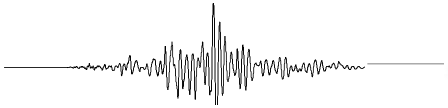
Outline

- Introduction
- Definition of the problem
- Structural classification of Industrial equipment and typical damages under seismic action
- Assessment methods for plant components: storage tanks
- Example: Seismic assessment of an elevated tank
- Example: Base Isolation of an elevated tank



Objectives

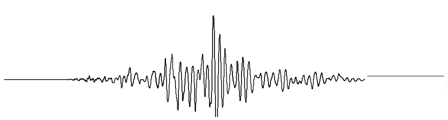
- Identification of the main industrial components (under structural point of view)
- Collection into a limited number of classes based of geometrical and mechanical characteristics
- Synthesis of the effects of earthquakes on the identified structural typologies of process components
- Description of assessment methods for storage tanks
- Analysis of a Case study
- Applicability of base isolation of the seismic protection of storage tanks



Definition of the problem

- Among events that can cause serious accidents to industrial plants, seismic action (**NATECH**) must be potentially considered one of the most important. As a matter of fact, in Italy about 30% of industrial plants with major-accident hazards are located in areas with a high seismic risk.

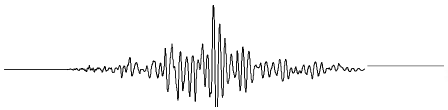
- In addition, in case of a seismic event, the earthquake can induces the simultaneous damage of more apparatus, which effects can result amplified because of the unsuccessful working of safety systems or because of the simultaneous generation of multiple accidental chains.



Definition of the problem

- The usual safety requirements applied to civil buildings (ultimate and serviceability limit states) are generally unsuitable for structures of industrial plants.

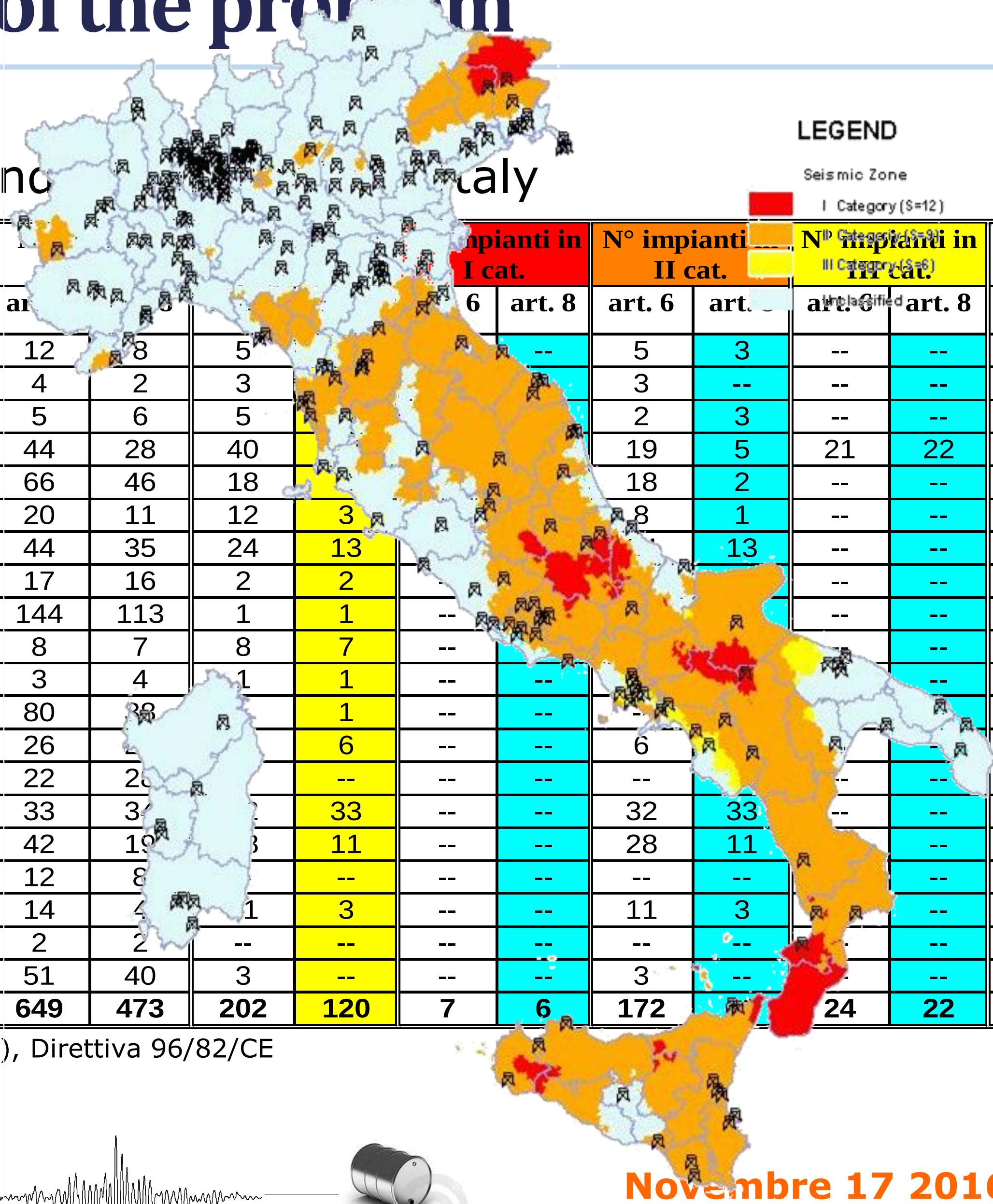
- As a matter of fact, a critical damage for a process safety that can cause an even modest release of inflammable substances, such as opening a flange or breaking a welding, or the simple friction between floating roof and tanks can result unessential from the structural damage point of view, but, at the same time, can cause considerable accidental chains.



Definition of the problem

Definition of the problem

Major Hazard industries in Italy

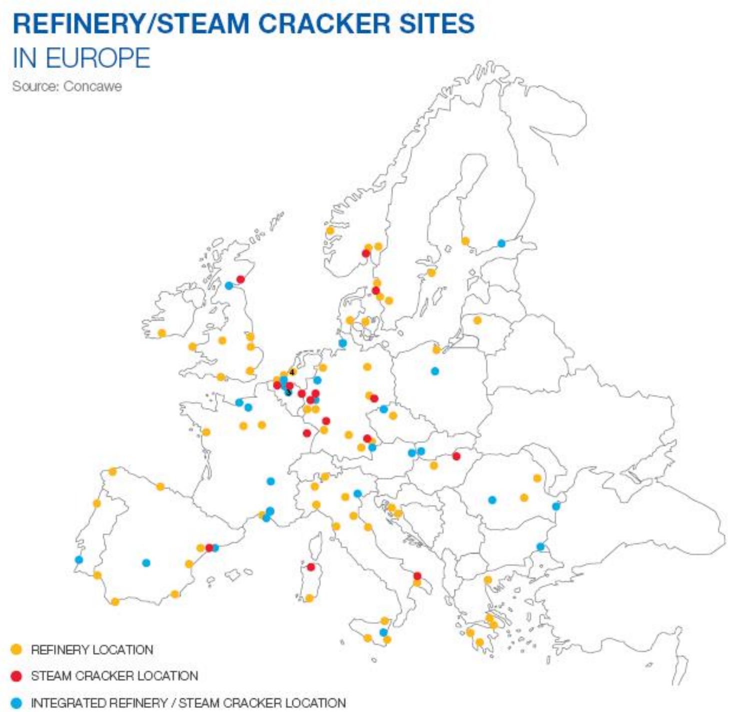


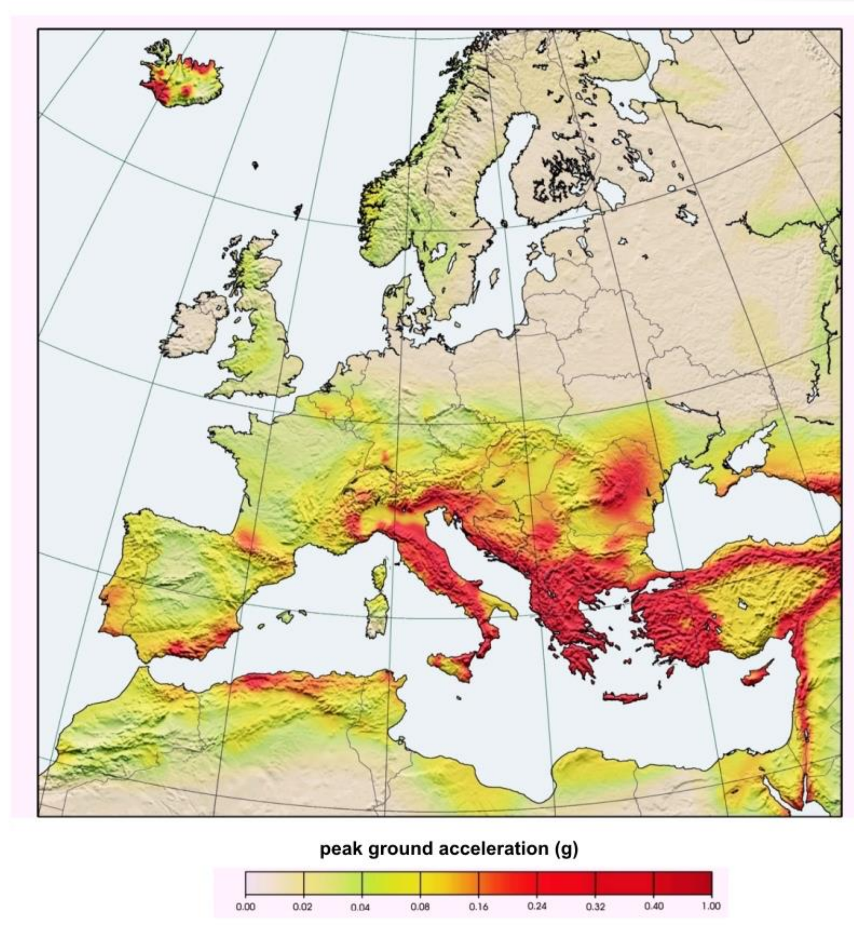
REGIONE	[illegible]		[illegible]		N° impianti in I cat.		N° impianti in II cat.		N° impianti in III cat.		% impianti in zona sismica	
	art. 6	art. 8	[illegible]	[illegible]	art. 6	art. 8	art. 6	art. 8	art. 6	art. 8	art. 6	art. 8
ABRUZZO	12	8	5	[illegible]	[illegible]	--	5	3	--	--	41,7%	37,5%
BASILICATA	4	2	3	[illegible]	[illegible]	[illegible]	3	--	--	--	75%	50%
CALABRIA	5	6	5	[illegible]	[illegible]	[illegible]	2	3	--	--	100%	100%
CAMPANIA	44	28	40	[illegible]	[illegible]	[illegible]	19	5	21	22	90,9%	96,4%
EMILIA-ROMAGNA	66	46	18	[illegible]	[illegible]	[illegible]	18	2	--	--	27,3%	4,3%
FRIULI-VEN.GIULIA	20	11	12	3	[illegible]	[illegible]	8	1	--	--	60%	27,3%
LAZIO	44	35	24	13	[illegible]	[illegible]	[illegible]	13	--	--	54,5%	37,1%
LIGURIA	17	16	2	2	[illegible]	[illegible]	[illegible]	[illegible]	--	--	11,8%	12,5%
LOMBARDIA	144	113	1	1	--	[illegible]	[illegible]	[illegible]	--	--	0,7%	0,9%
MARCHE	8	7	8	7	--	[illegible]	[illegible]	[illegible]	[illegible]	--	100%	100%
MOLISE	3	4	1	1	--	--	[illegible]	[illegible]	[illegible]	--	33,3%	25%
PIEMONTE	80	[illegible]	[illegible]	1	--	--	[illegible]	[illegible]	[illegible]	[illegible]	--	2,6%
PUGLIA	26	[illegible]	[illegible]	6	--	--	6	[illegible]	[illegible]	[illegible]	34,6%	25%
SARDEGNA	22	[illegible]	[illegible]	--	--	--	--	[illegible]	[illegible]	--	--	--
SICILIA	33	34	[illegible]	33	--	--	32	33	--	--	97%	97,1%
TOSCANA	42	19	[illegible]	11	--	--	28	11	[illegible]	--	66,7%	57,9%
TRENTINO-ALTO ADIGE	12	8	[illegible]	--	--	--	--	--	[illegible]	--	--	--
UMBRIA	14	4	[illegible]	3	--	--	11	3	[illegible]	--	78,6%	75%
VAL D'AOSTA	2	2	--	--	--	--	--	--	[illegible]	--	--	--
VENETO	51	40	3	--	--	--	3	--	[illegible]	--	5,9%	--
ITALIA	**649**	**473**	**202**	**120**	**7**	**6**	**172**	[illegible]	**24**	**22**	**31,1%**	**25,4%**

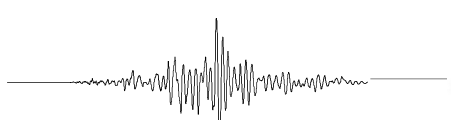
D. Lgs. 334/99 (Seveso II), Direttiva 96/82/CE

Definition of the problem

Refinery plants in Europe

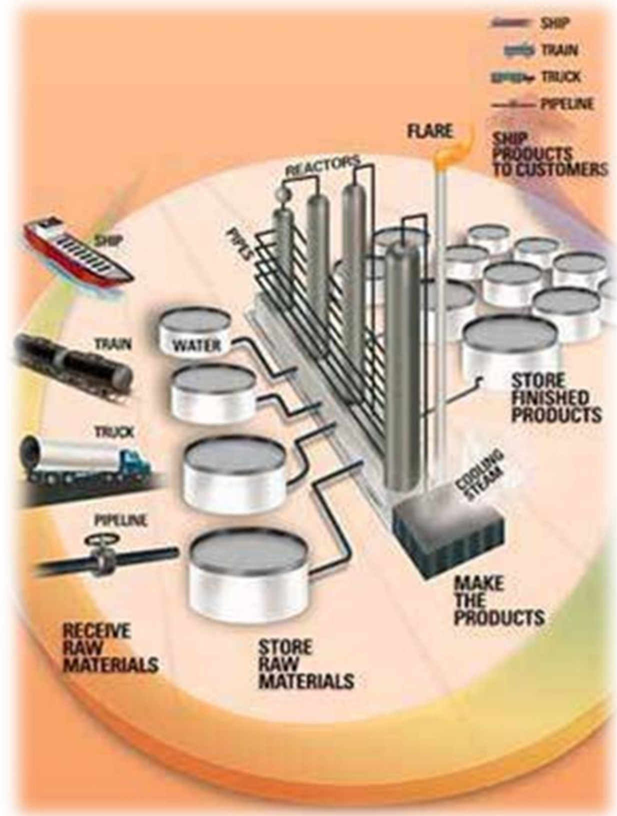




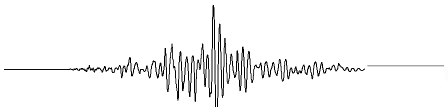


Equipment of a petrochemical plant

General view of a Petrochemical plant



Process flow of a Petrochemichal plant (Moulein & Makkee, 1987)

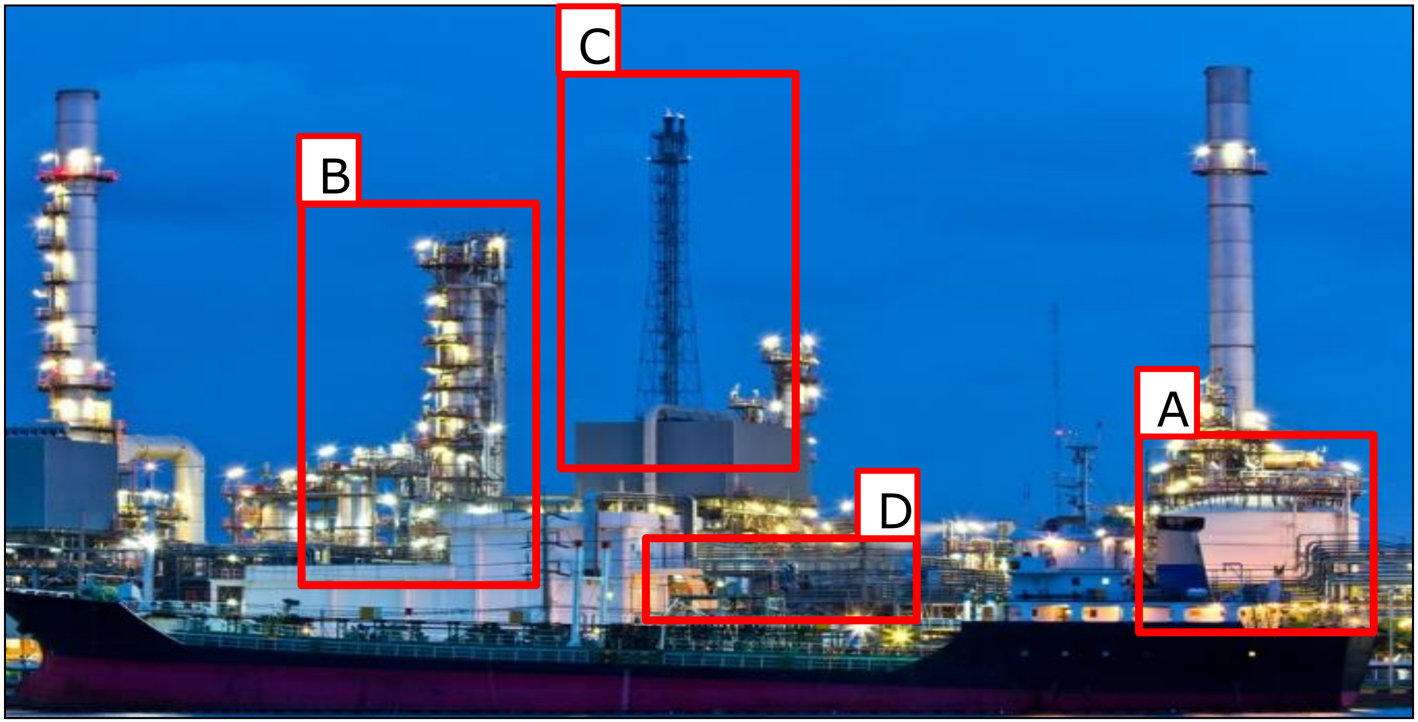


Equipment of a petrochemical plant

Typical layout of a Petroleum Refinery

Equipment of a petrochemical plant

Main components of a Petroleum refinery

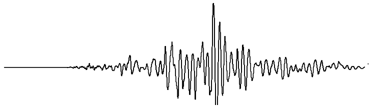


A Storage Tanks

B Process Equipment

C Torches and flares

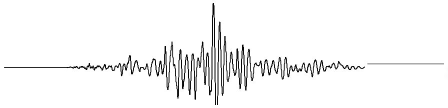
D Pipelines



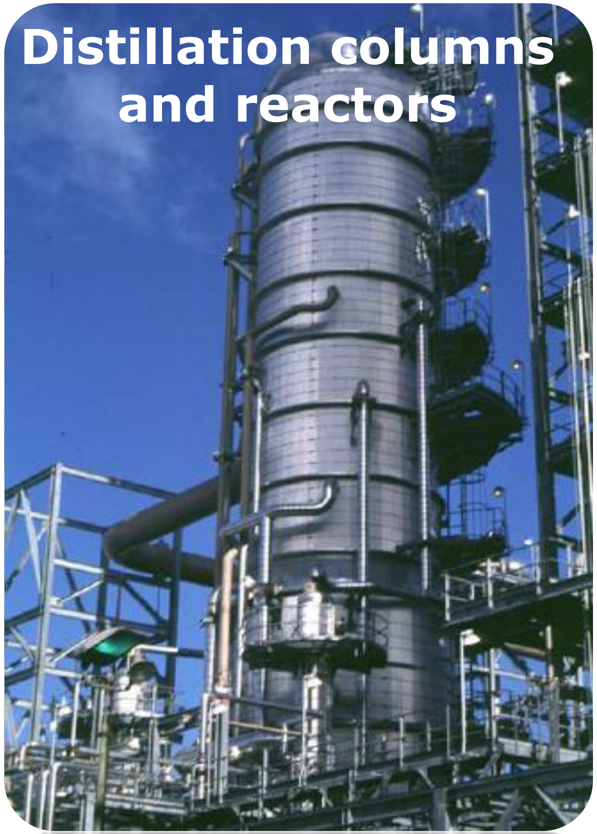
Structural classification and typical seismic damages

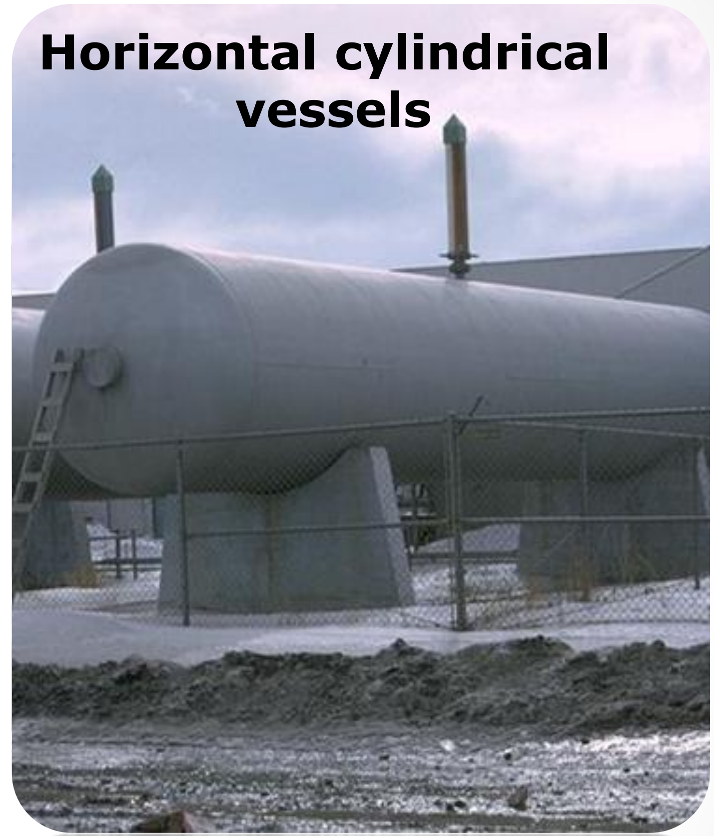
- Slim vessels
- Squat equipment directly placed on the foundation
- Squat equipment supported by columns
- Piping, pipelines and supporting structures

F. Paolacci, R. Giannini, M. De Angelis, (2013), Seismic response mitigation of chemical plant components by passive control systems, *Journal of Loss Prevention in Process Industries, Volume 26, Issue 5, Pages 879-948 Special Issue: Process Safety and Globalization* - **DOI:10.1016/j.jlp.2013.03.003.**



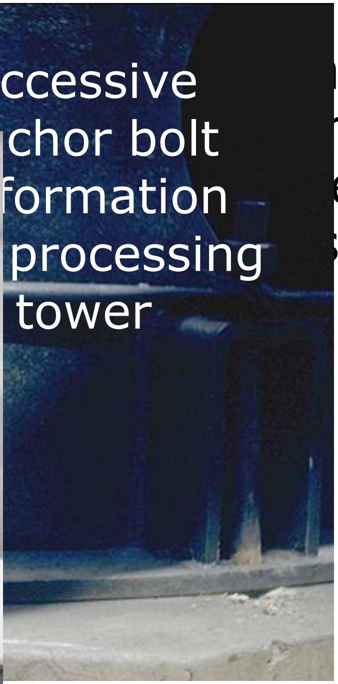
Structural classification: **SLIM VESSELS**





Structural classification: **SLIM VESSELS (typical damages)**

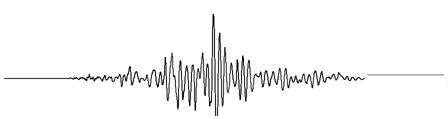
- the mos … ic event are the … n due to … ed fluids … due to



Failure of a stack, Itzmit 1999

Structural classification:
Squat eq. directly placed on the foundation

- These apparatus are characterized by heavy masses;
- the main category of structures belonging to this group is the large cylindrical steel storage tanks with a height/diameter ratio between 0.2 and 2. The roof can be welded to the shell (fixed conic roof) or floating over the contained liquid. The operating volume varies from some tens to 200000 m^3.



Structural classification:

Squat eq. directly placed on the foundation (Typical damages)

- The ... ctures are rela... phant foot buc... the tank bot...
- Oth... excessive slo... ating roof, wh... due to the cra...
- Upl...

Structural classification:
Squat eq. supported by columns

Spherical storage vessels

Cylindrical elevated tanks

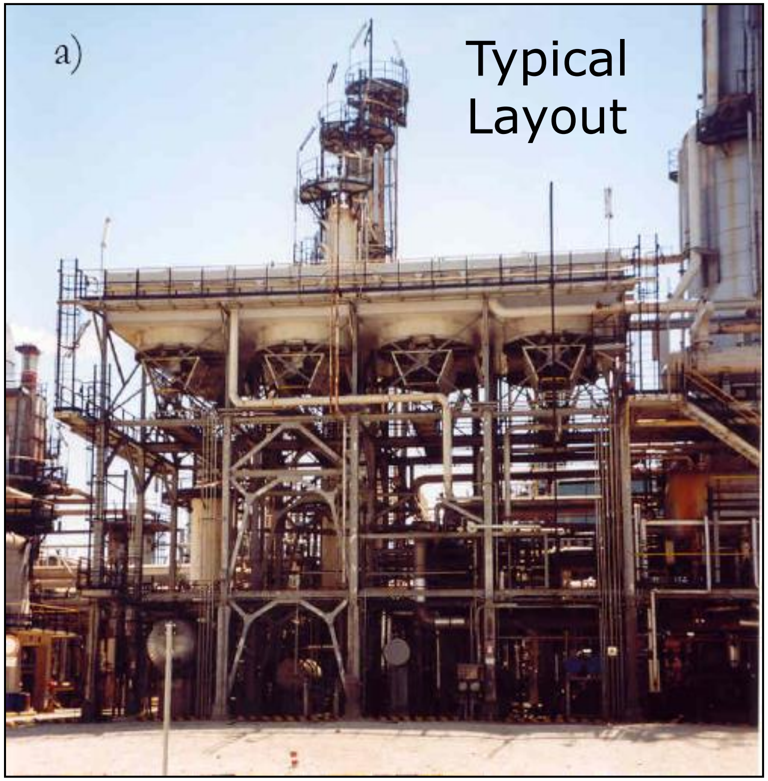
Cylindrical or Cathedral-type Heaters

Structural classification:

Squat eq. supported by columns (typical damages)

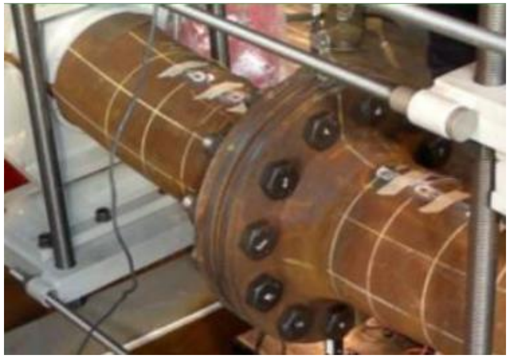
Fire due to the disconnection of the pipes-tanks joints

Structural classification:
Pipes, pipelines and support structure



Structural classification:

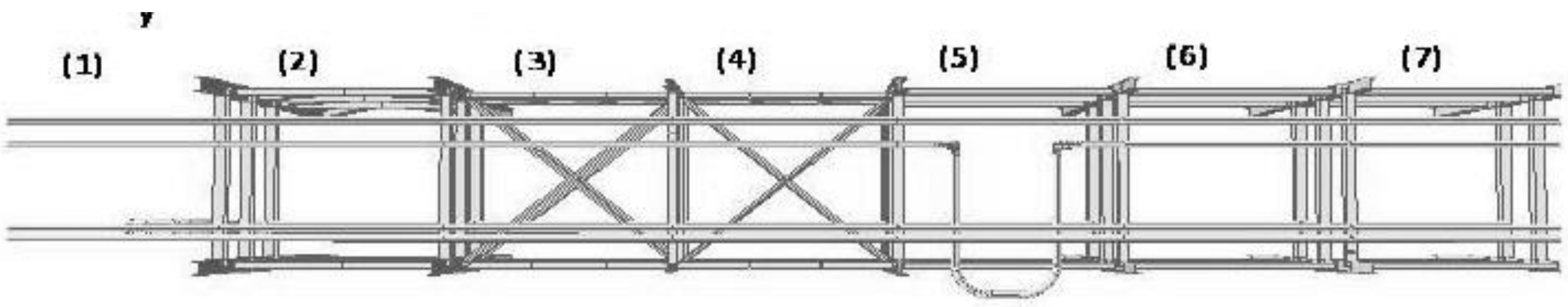
Pipes, pipelines and support structure



Flange Bolted Joints

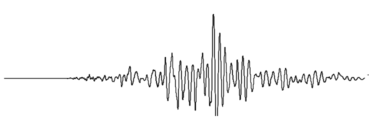
Elbows

Tee-joints

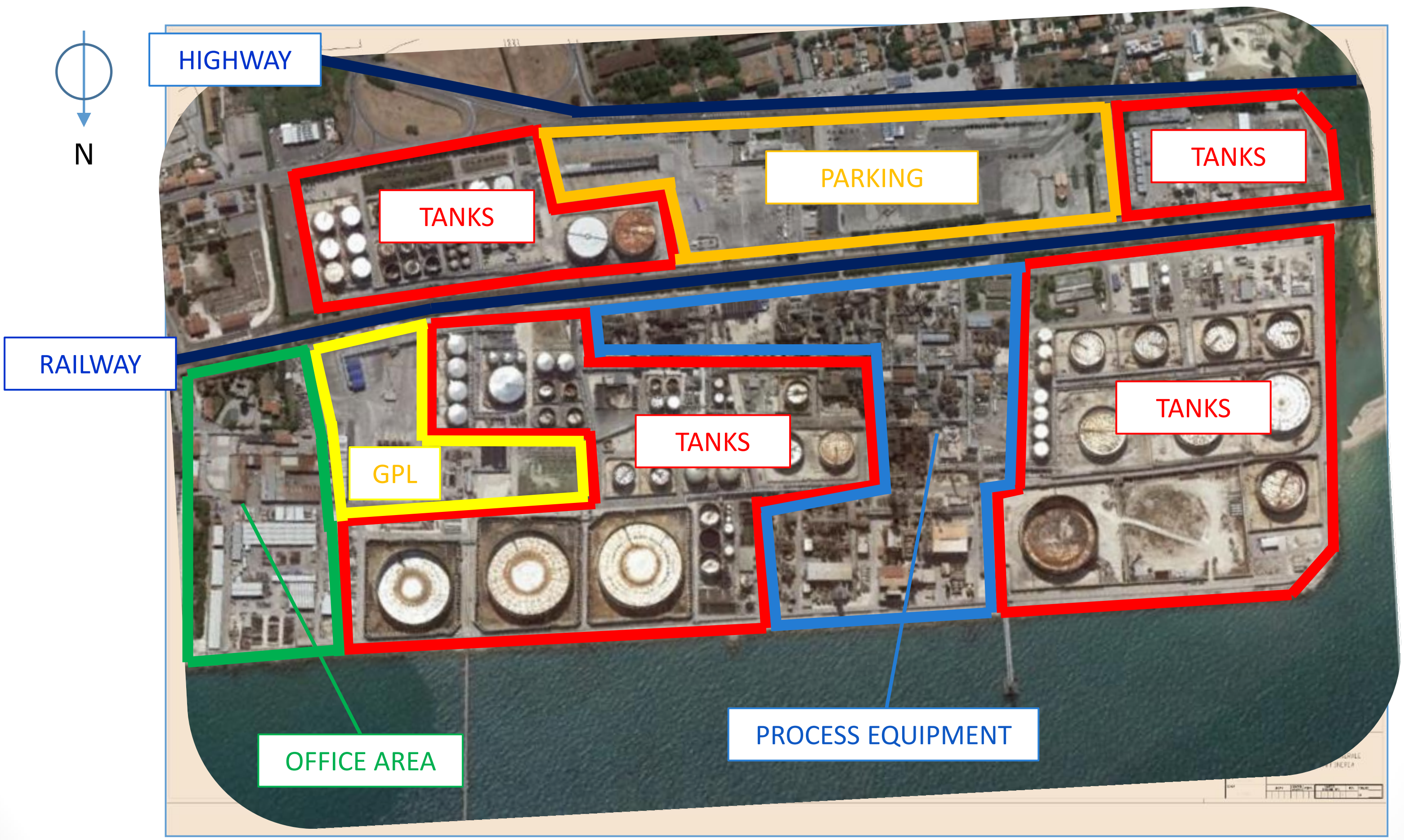


Typological and damage-based classification of plant components

Structural typology	Critical equipment	Typical seismic observed damages	Other possible damages
Slim vessels	**Columns** **Reactors** **Chimney** **Torch**	• Leakage of fluid in flanged joints • Yielding of anchor bars	**Overturning**
Above-ground squat equipment	Big broad tanks with fixed and floating roof	**Failure of wall-bottom plate welding** **Elephant foot buckling** **Diamond buckling of tank wall** **Settlements of ground** **Impact of floating roof to tank wall.**	**Uplifting** **Overtopping** **Torch fire**
Squat equipment placed on short columns	**Spherical tanks**	**Collapse of structure due to shear failure of columns**	
	Process Furnaces	**Collapse of structure due to shear failure of columns** **Collapse of the chimney** **Detachment of internal pipes** **Detachment of the internal refractory material**	**Leakage from pipes;** **Increase of temperature of Furnace wall**
	Cryogenic tanks	**Collapse of structure due to shear failure of columns**	
Piping systems and support structure	**Steel or R.C. frames**	**Collapse for excessive stresses**	**Damages to supported equipment (pipes, tanks,..)**




Seismic assessment methods for plant components
storage tanks



Seismic assessment methods for plant components
storage tanks

Limit States for tanks

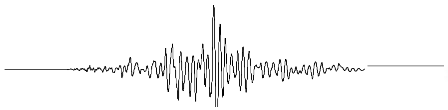
Typologies of tanks

storage tanks

The assessment of seismic vulnerability of storage tanks, is usually performed using the well-know concept of Fragility: the probability of exceeding of a certain limit state, P(D>LS| PGA). It is evaluated for different values of selected Intensity Measures. A suitable IM for tanks often adopted in literature is the PGA.

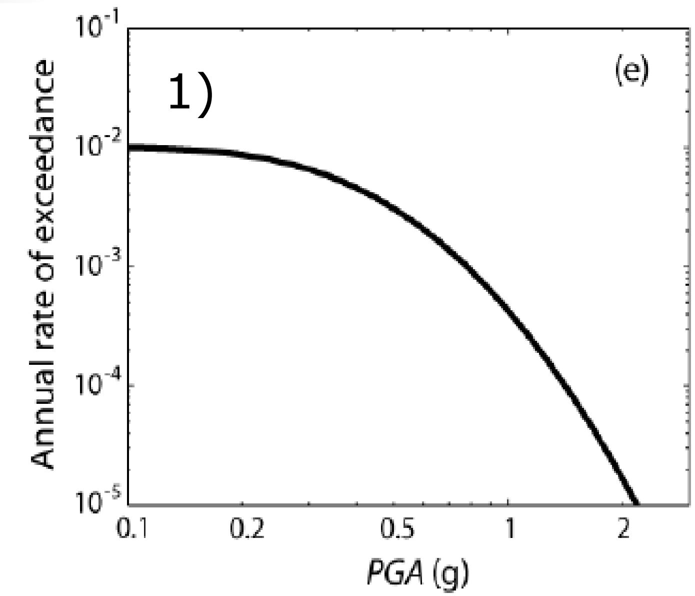
The main steps to evaluate fragility curves are the following:

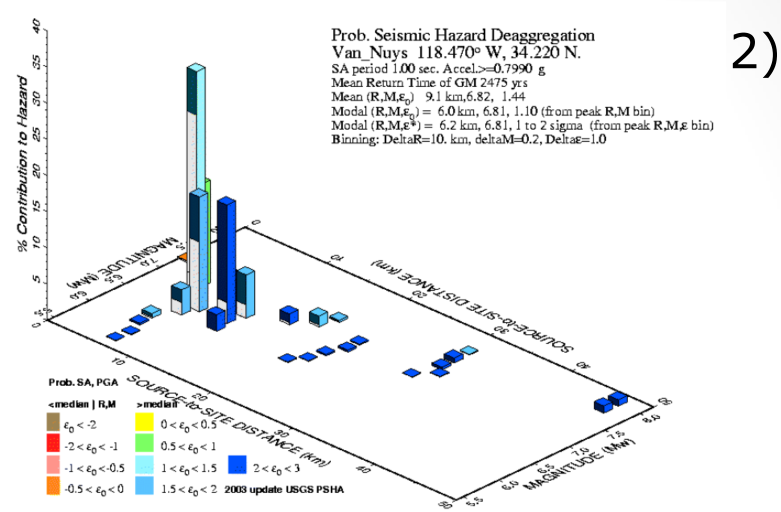
- Definition of hazard and input signals
- Definition of Dynamic models
- Definition of Limit States
- Calculation of probability of failure

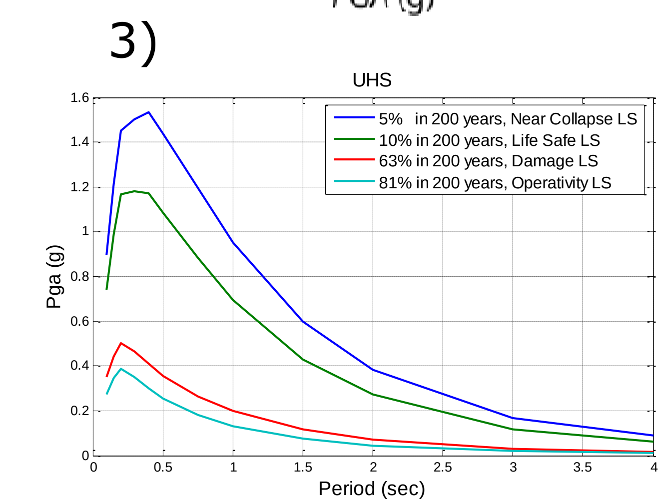


Assessment methods for plant components: storage tanks

1. **Seismic Hazard and input signals**

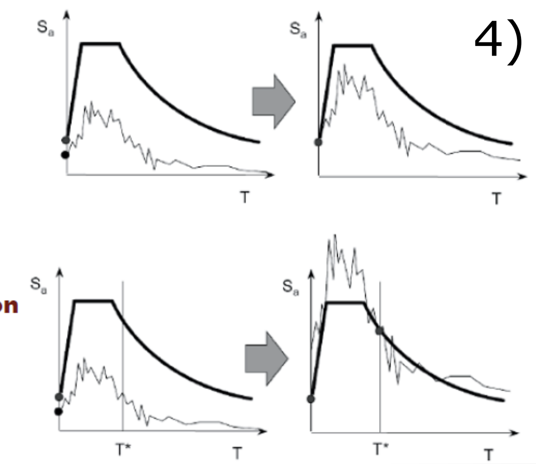


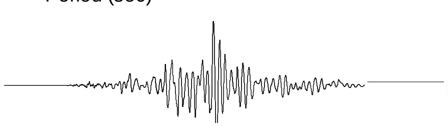




Match to Peak Ground Acceleration (PGA)

Match Spectral Acceleration at Specific Period





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Assessment methods for plant components: storage tanks
2. **Dynamic modeling**

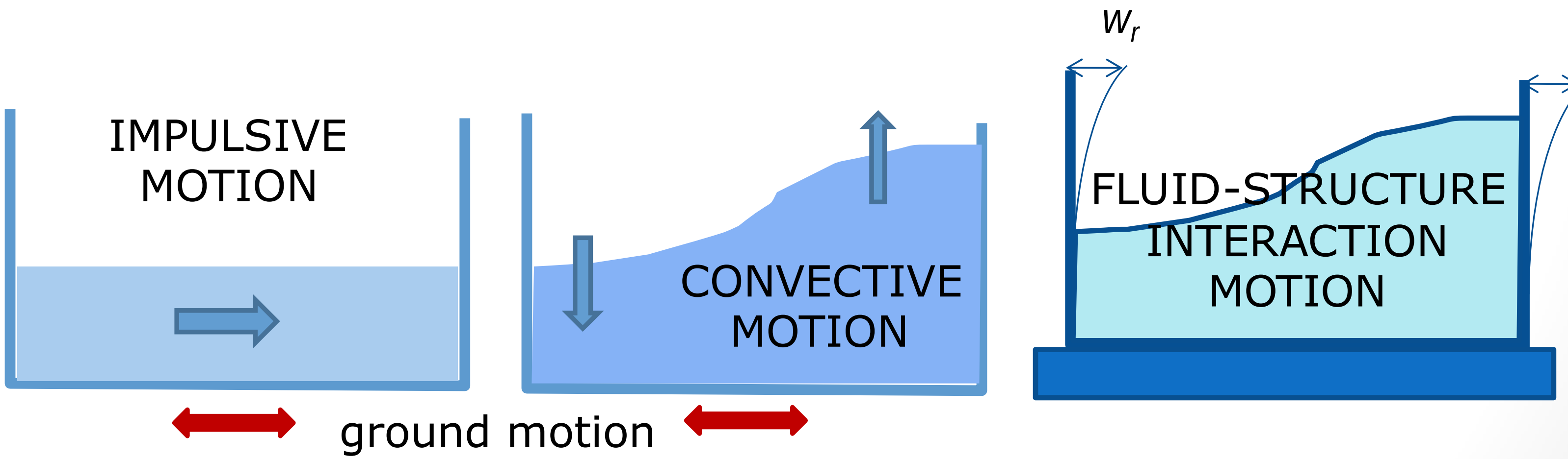
Hypotesis

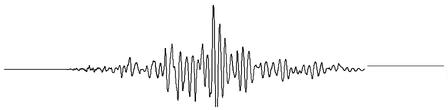
- “Perfect Liquid “ (unviscous and uncompressible)
- Laminar and slow motion
- Free liquid surfaces

$$\mathbf{v} = \mathrm{grad}(\phi)$$

Laplace Equation

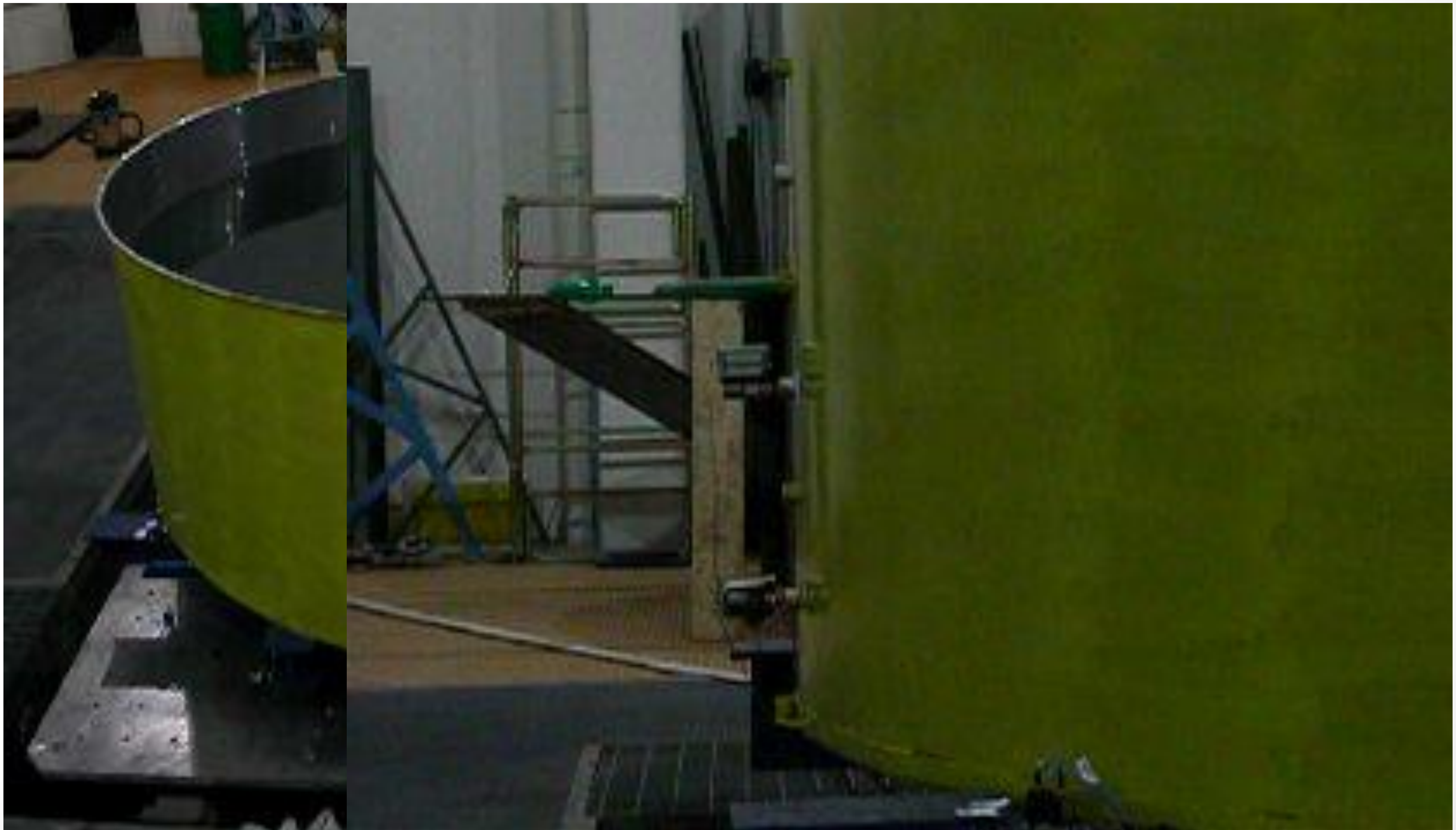
$$\Delta\phi = \frac{\partial^2\phi}{\partial x^2} + \frac{\partial^2\phi}{\partial y^2} + \frac{\partial^2\phi}{\partial z^2} = 0$$



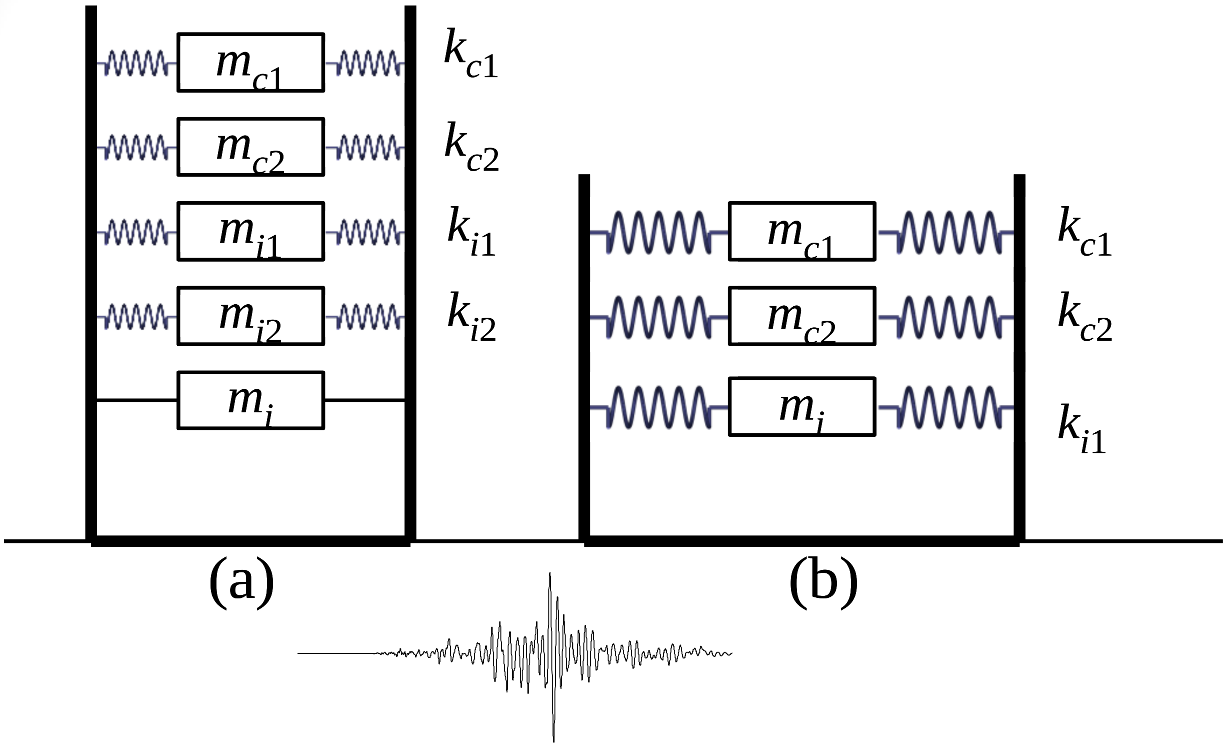


Assessment methods for plant components: storage tanks
2. **Dynamic modeling**

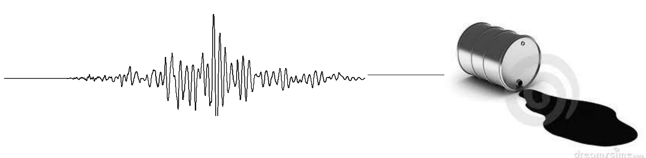
M. De Angelis, R. Giannini, F. Paolacci, (2010), Experimental investigation on the seismic response of a steel liquid storage tank equipped with floating roof by shaking table tests, Earthquake Engineering & Structural Dynamics, 39: 377–396. DOI: 10.1002/eqe.945



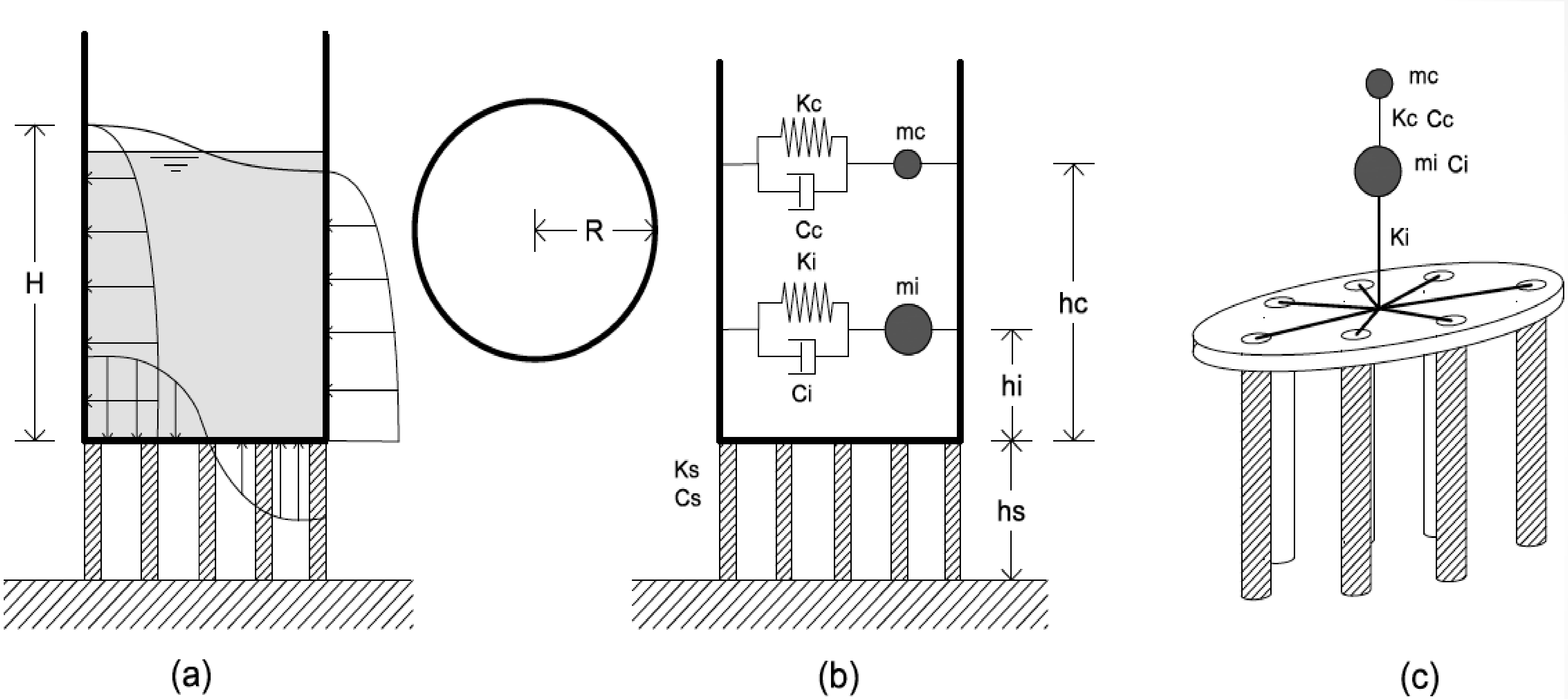
2. **Dynamic modeling**



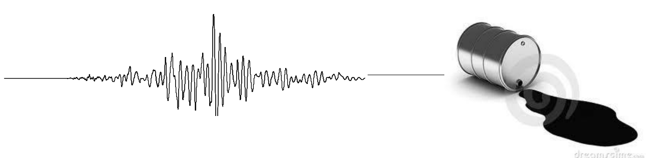
Lumped mass models of tanks: (a) Slender, (b) Broad



2. **Dynamic modeling**



Lumped mass models of elevated tanks



Assessment methods for plant components: storage tanks
3. **Definition of limit states**

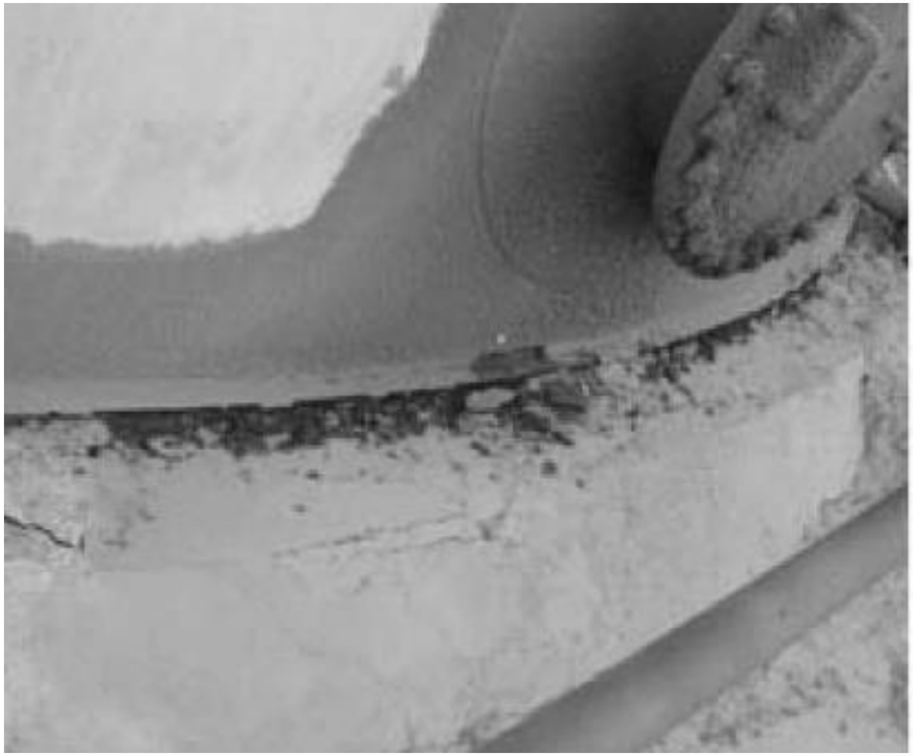
- Damages are in the form of cracking at the corner of the bottom plate and buckling of tank wall due to uplift, sliding of the base, anchorage failure, sloshing damage around the roof, failure of piping systems and plastic deformation of base plate.

ELASTOPLASTIC BUCKLING
(Elephant's Foot)

ELASTIC BUCKILING
(Diamond shape)

Assessment methods for plant components: storage tanks
3. **Definition of limit states**

OVERTOPING



UPLIFTING

3. **Definition of limit states**

Each Damage State can be quantified analytically using for example the analytical formula provided by the current regulations. Buckling problems have been well solved in literature whose solutions are included in most of the standards and codes. For example:

Elephant foot buckling (EN1998:4)

$$f_{pb} = \sigma_{c1} \cdot \left[1 - \left(\frac{p \cdot R}{t_w \cdot f_y} \right)^2 \right] \cdot \left(1 - \frac{1}{1.12 + r^{1.5}} \right) \cdot \left(\frac{r + f_y/250}{r + 1} \right),$$

where $\sigma_{c1} = 0.605 \frac{E_w t_w}{R}$ is the Euler's critical axial compressive stress, R is the tank radius, p is the total internal pressure, E_w and t_w are the elastic modulus and the thickness of the tank walls, f_y is the steel yielding stress, and r is a coefficient defined as $r = R/(400 \cdot t)$.

4. **Calculation of Fragility curves**

- The structural fragility can be defined as the probability of exceeding a selected Limit State (LS) for a specified the Intensity Measure (IM).
- A lognormal cumulative distribution function is often used to define a fragility function:

$$P[D_{EDP} > LS \mid IM] = \Phi\left(\frac{\ln\left(IM / \mu\right)}{\beta}\right)$$

median of the fragility function (μ)

probability of exceeding a selected *LS* for a specified *IM* ($P[D_{EDP} > LS \mid IM]$)

standard deviation of ln*IM* (dispersion of *IM*) (β)

4. **Calculation of Fragility curves**

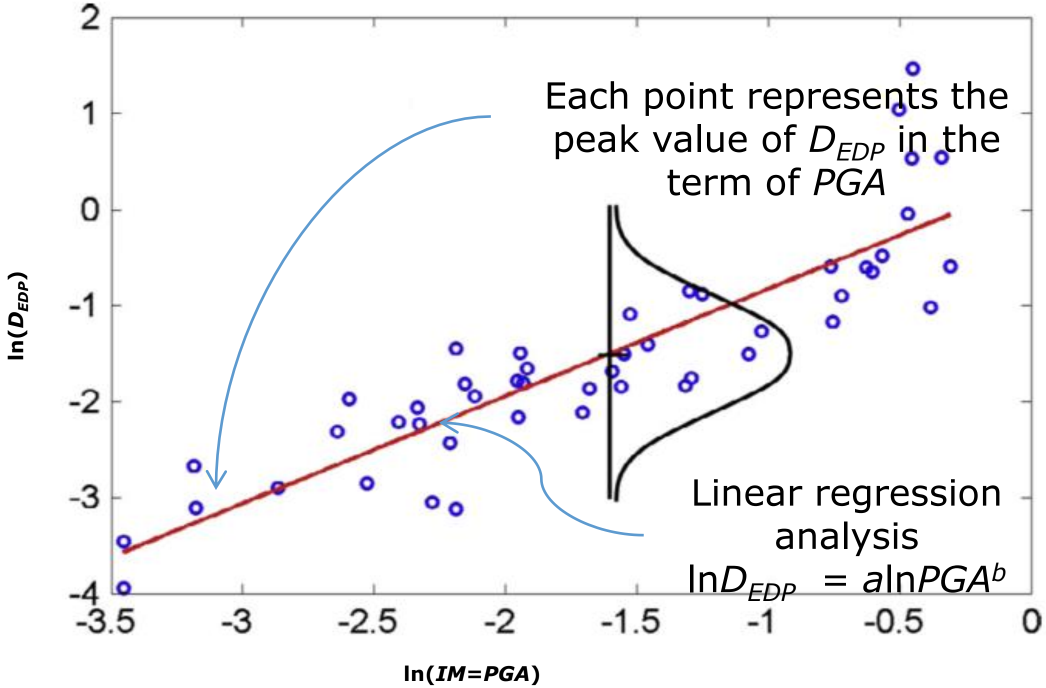
- Non-linear dynamic analysis procedures → relationship between EDP and IM:
  - Cloud Method (Bazzurro et al. 1998; Luco and Cornell 1998; Jalayer 2003)
  - Incremental Dynamic Analysis (IDA) (Vamvatsikos and Cornell 2002)
  - Multiple-Stripe Analysis (MSA) (Bazzurro et al. 1998; Baker 2007; Jalayer and Cornell 2009)

Assessment methods for plant components: storage tanks
4. **Calculation of Fragility curves: Cloud Analysis**

- Cloud Analysis method uses a set of un-scaled ground motion records.
- This method implements the non-linear dynamic analysis results in a (linear) regression-based probabilistic model.
- Assumption of a constant conditional standard deviation for probability distribution of the EDP given IM.
- Strong dependence on the suite of ground motion records.

Assessment methods for plant components: storage tanks

4. **Calculation of Fragility curves: Cloud Analysis**



Example: Cloud Analysis results

$$D_m = a\left(IM\right)^b$$

mean

a and b are regression coefficients based on the collection of d_i and IM_i .

$$\beta_{d|IM} = \sqrt{\frac{\sum_{i=1}^{n}\left[\ln\left(d_i\right) - \ln\left(aIM_i^b\right)\right]^2}{n-2}}$$

Dispersion

4. Calculation of Fragility curves : Cloud Analysis

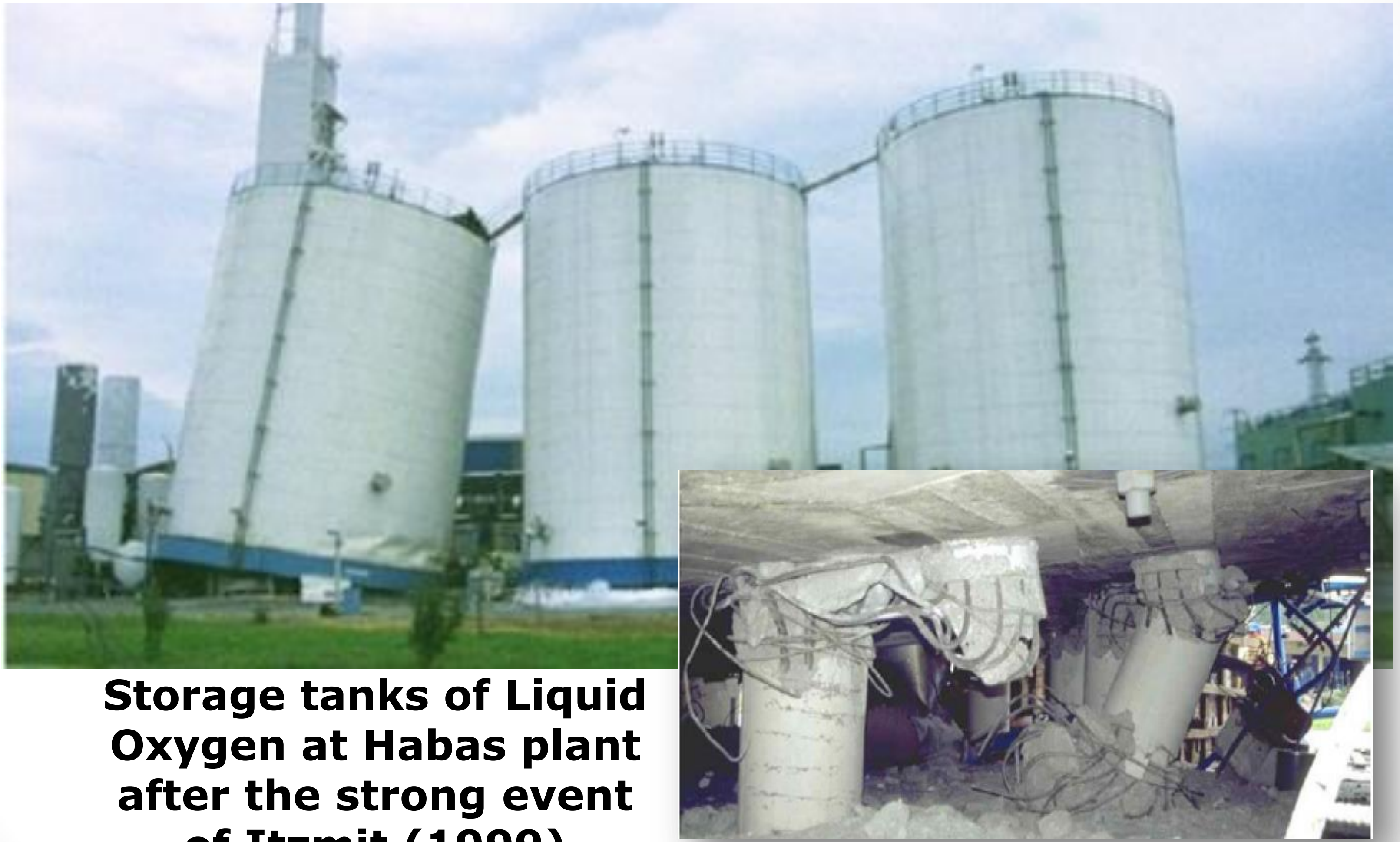
- When the seismic demands and the structural limit states are assumed to follow a lognormal distribution, the probability of exceeding a specific damage state can be given as:

$$P\left[D_{EDP} > LS \mid IM\right] = 1 - \Phi\left(\frac{\ln\left(LS_m\right) - \ln\left(D_m\right)}{\sqrt{\beta_{d|IM}^2 + \beta_{LS}^2}}\right)$$

Φ	standard normal cumulative distribution function
LS_m	median estimate of the structural limit state
D_m	median estimate of the demand
$\beta_{d\|IM}$	dispersion of the demand conditioned on the IM
β_{LS}	dispersion of the structural limit state

Assessment methods for plant components: storage tanks

Example: Fragility curves evaluation of an LNG tank

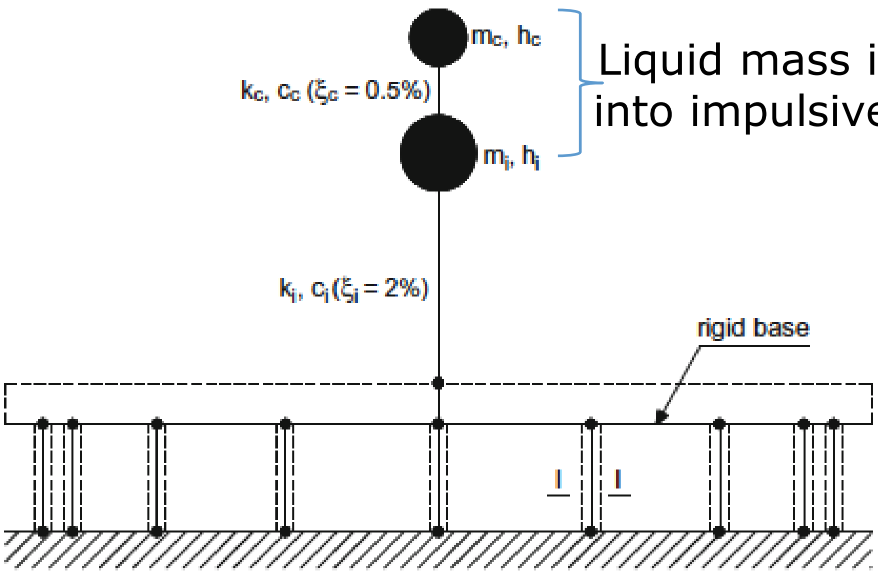


Storage tanks of Liquid Oxygen at Habas plant after the strong event of Itzmit (1999)

Assessment methods for plant components: storage tanks

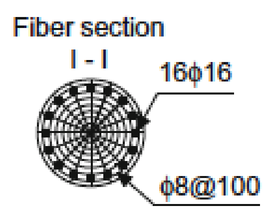
Example: Fragility curves evaluation of an LNG tank

- 3D nonlinear modeling



Liquid mass is lumped and subdivided into impulsive and convective masses.

Sketch of 3D model (OPENSEES)

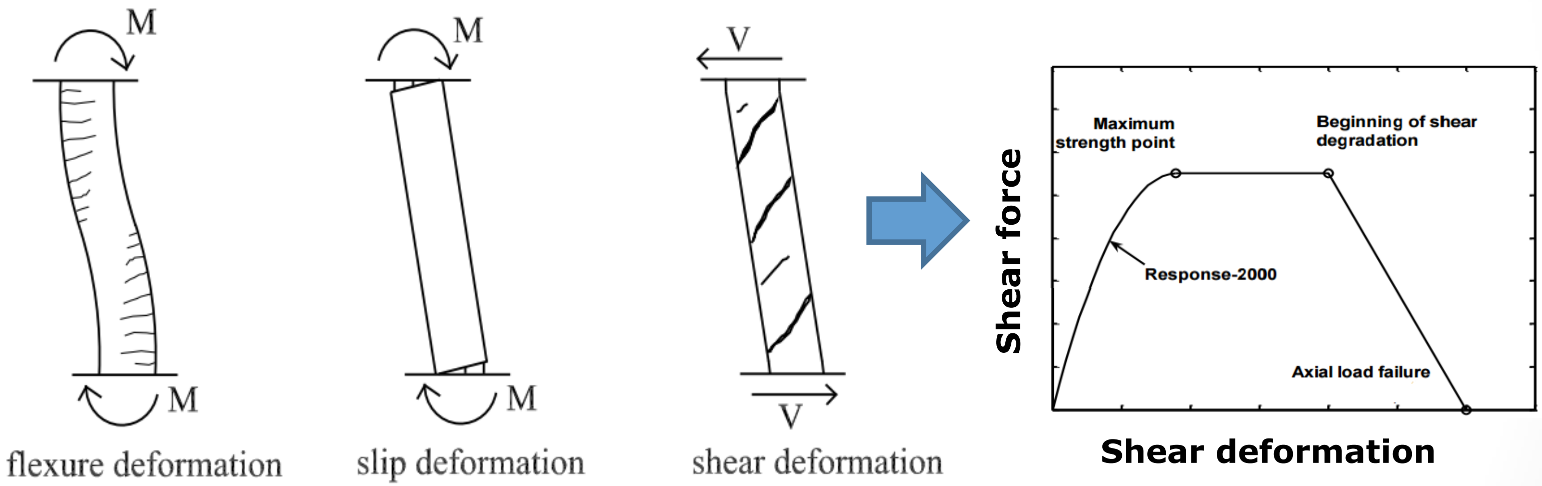


RC columns are modeled using 3D nonlinear elements with fiber-defined cross-sections

Assessment methods for plant components: storage tanks

Example: Fragility curves evaluation of an LNG tank

- Columns with small aspect ratio or without adequate shear-resisting reinforcement, shear deformation governs the total response → unexpected shear or shear-flexure failure.

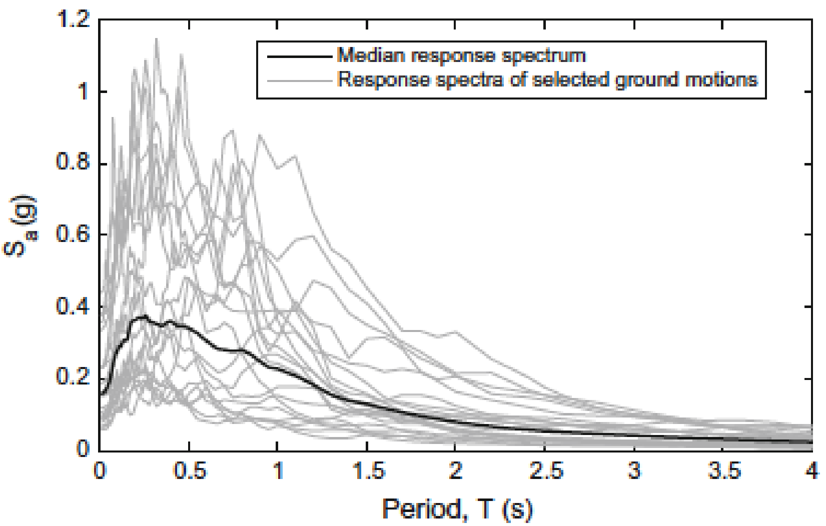


The total lateral deformation of a fixed-ended RC column: flexural, reinforcement slip, and shear deformations.

Assessment methods for plant components: storage tanks

Example: Fragility curves evaluation of an LNG tank

- The system was subjected to 20 natural records selected from PEER Strong Ground Motion:
  - Database Magnitude: 5<M< 7
  - Distance from the fault: 0<d< 20 km
  - S-waves velocity between 360 m/s and 760 m/s



Response spectra of the 20 unscaled accelerograms

Example: Fragility curves evaluation of an LNG tank

- **Engineering Demand Parameters (EDP):**
  - Drift ratio $q = \frac{d}{H_{col}}$
  - Compressive meridional stress (**API 650**)

$$s_z = \frac{1}{t_s}\left(w_t \left(1 + 0.4 a_{gv}\right) + 1.273 \frac{M_T}{D^2} \right)$$

  - Elevation of liquid free surface (**EN1998:4**)

$$d_{\max} = 0.84 R S_a \left(T_c\right) / g$$

Assessment methods for plant components: storage tanks

Example: **Fragility curves evaluation of an LNG tank**

- **Limit states:**
  - Ultimate Drift ratio at pure-shear failure

$$q_{LS} = 0.245\%$$

(*)

Drift ratio for pure flexural failure (Chord Rotation)

$$q_{LS} = 0.360\%$$

EN 1998-4

- Meridional design buckling stress (EN 1998-4)

$$\sigma_{x,Rd} = \sigma_{x,Rk} / \gamma_{M1} = \left(\chi_x \sigma_y\right) / \gamma_{M1}$$

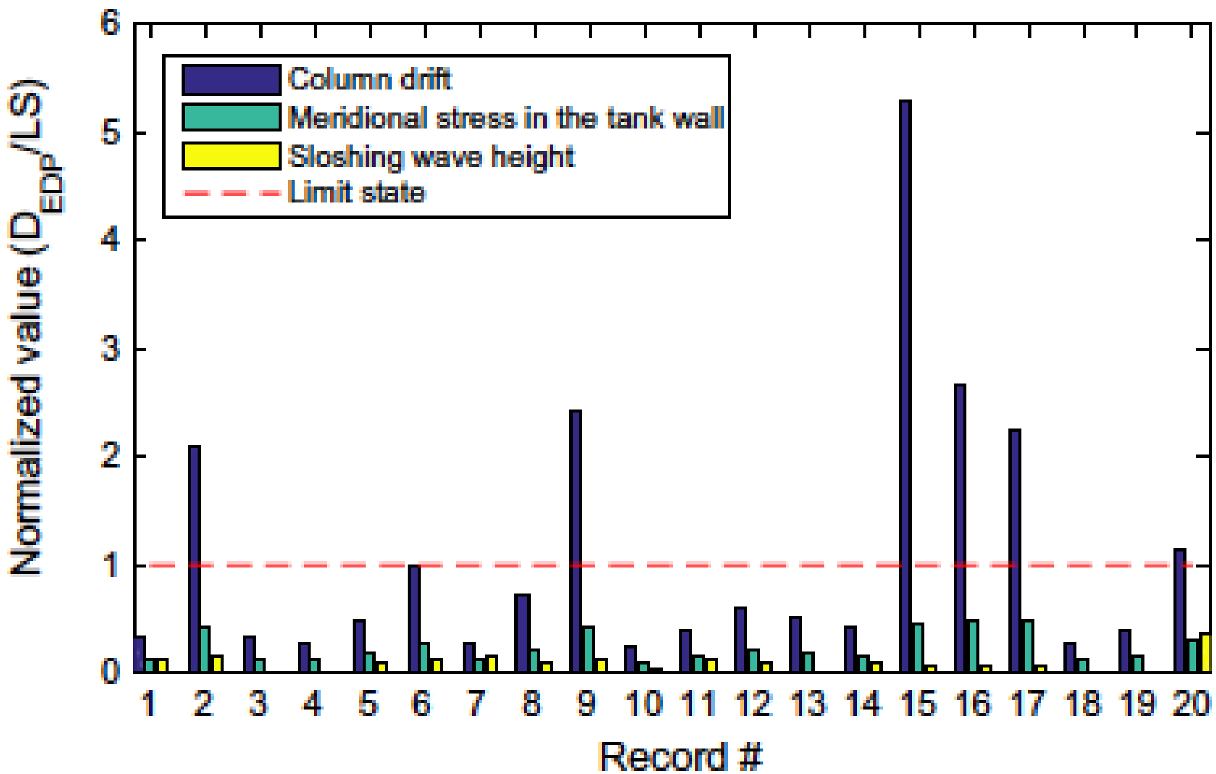
- Free board height:

$$d_{LS} = H_{tank} - H_{liquid}$$

(*) M. Gerin and P. Adebar (2004) **Accounting for Shear in Seismic Analysis of Concrete Structures** 13th World Conference on Earthquake Engineering (WCEE), Vancouver, Canada, August 2004

Assessment methods for plant components: storage tanks

Example: Fragility curves evaluation of an LNG tank

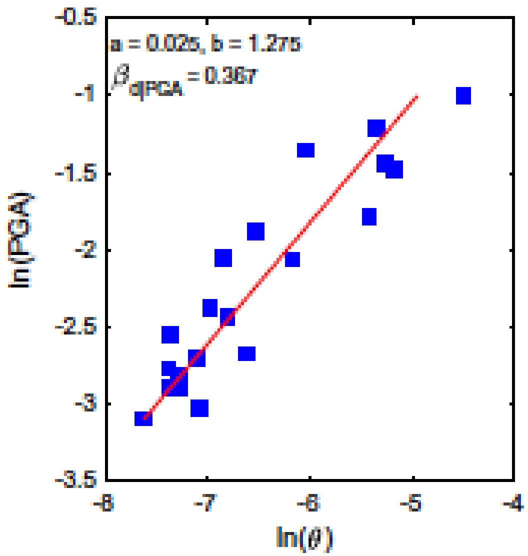


Seismic Demand Parameters

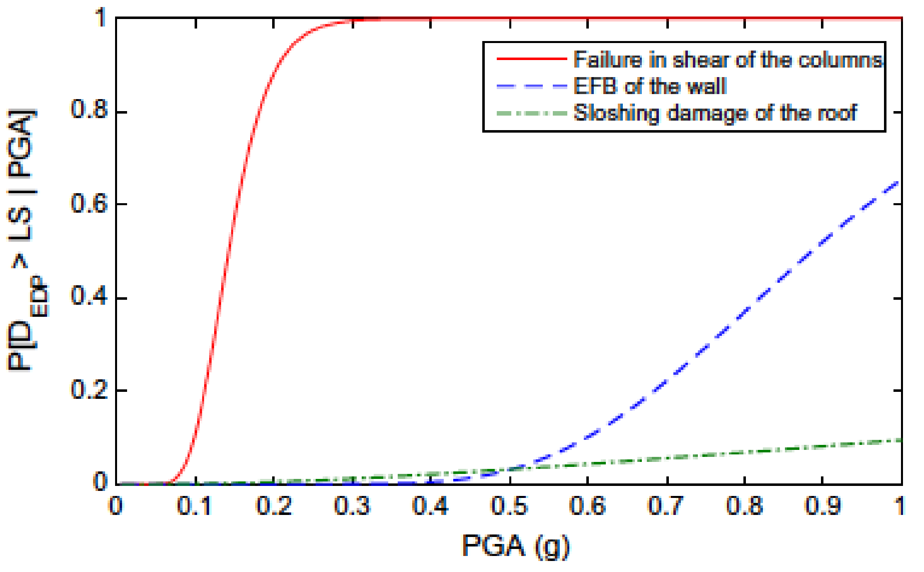
Assessment methods for plant components: storage tanks

Example: **Fragility curves evaluation of an LNG tank**

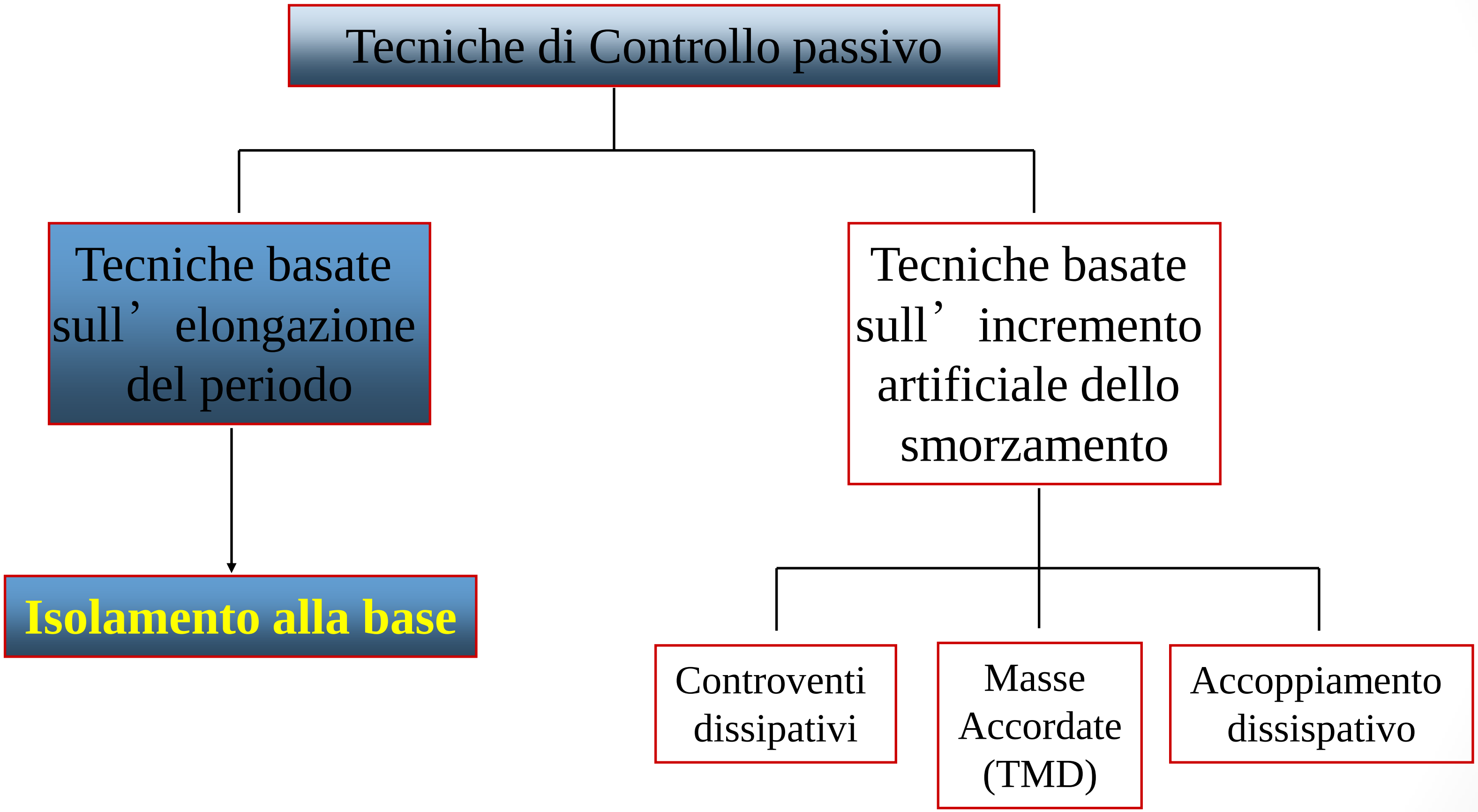
Probabilistic Seismic Response Analysis (Cloud Analysis)



Fragility curve for shear failure of columns

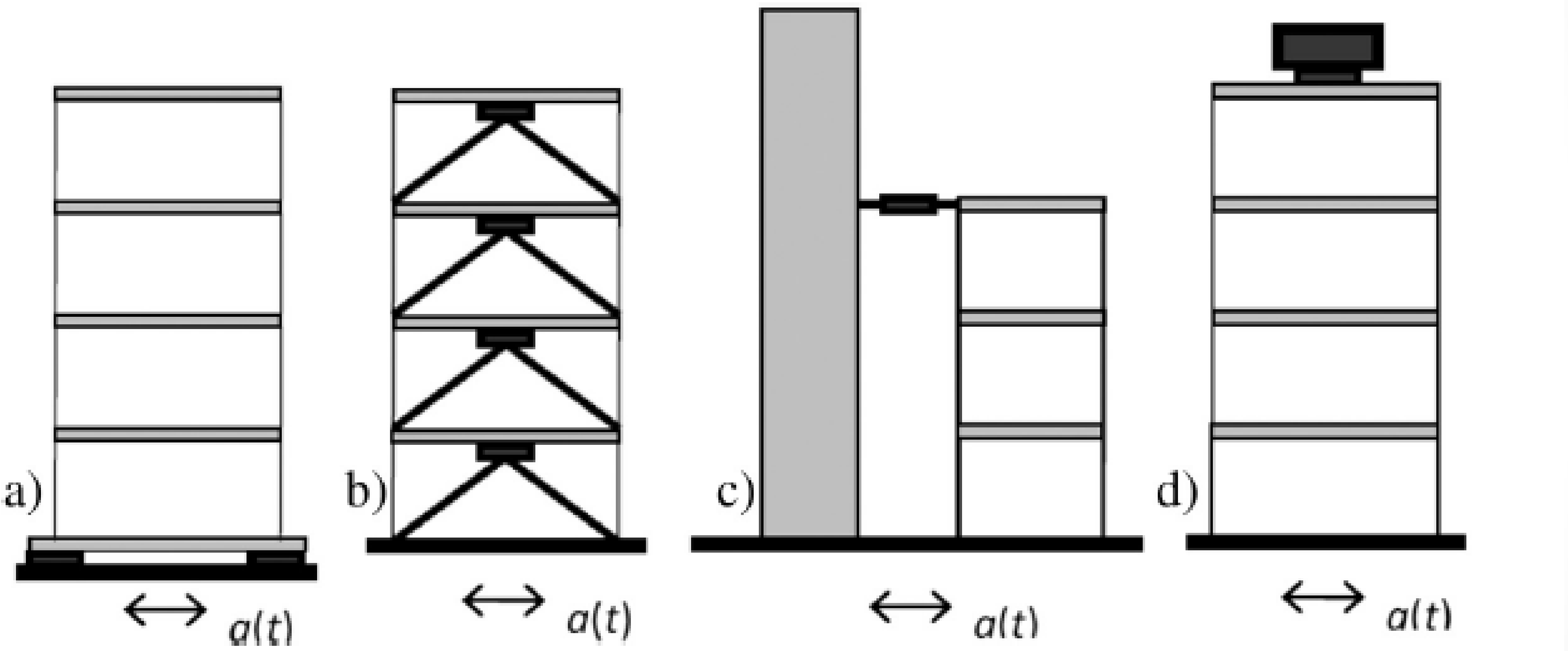


Passive Control Systems



Seismic protection of Industrial Components

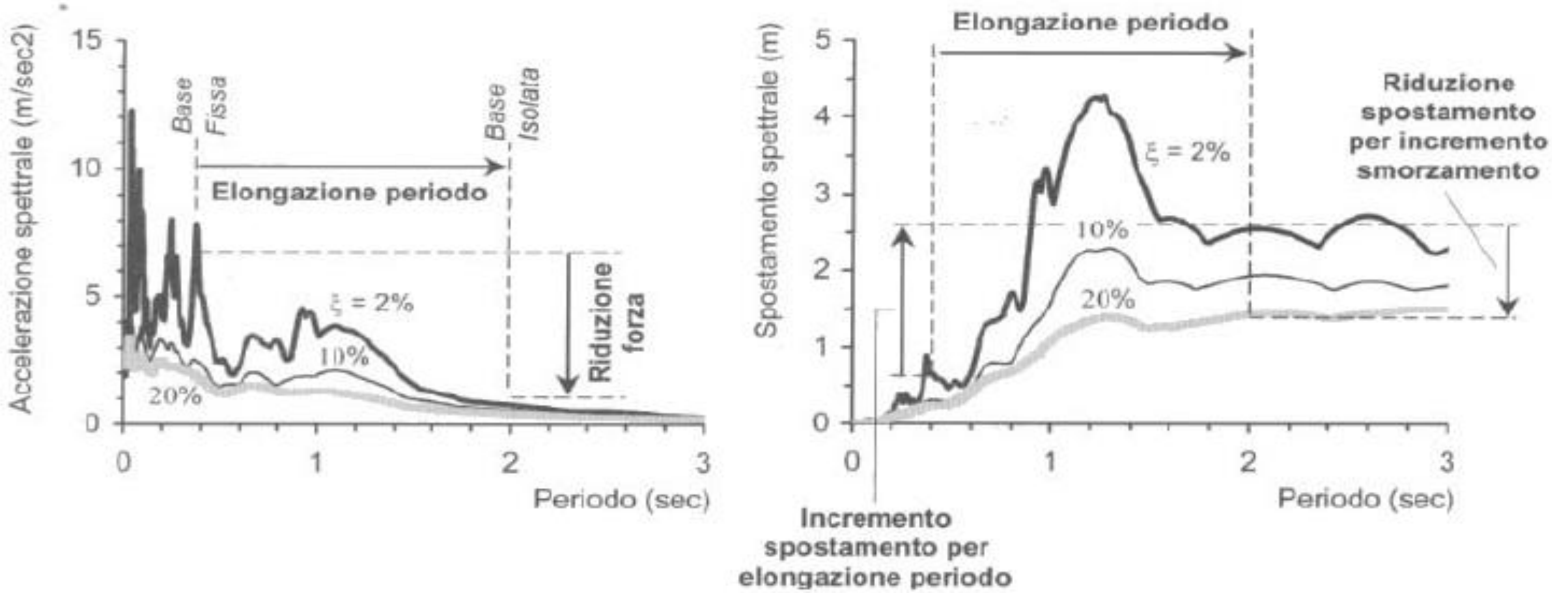
Passive Control Systems



Passive Control Systems

Principi di funzionamento dei SCP

Dolce ed al. “ progetti di edifici isolati alla base” , IUSS Press



Seismic protection of Industrial Components

Passive Control Systems

Seismic damages of industrial process components and passive control techniques.

Structural typology	Critical equipment	Typical seismic observed damages	Other possible damages	Passive control techniques
Slim vessels	Columns Reactors Chimney Torch	• Leakage of fluid in flanged joints • Yielding of anchor bars	Overturning	Dissipative coupling
Above-ground squat equipment	Big broad tanks with fixed and floating roof	Failure of wall-bottom plate welding Elephant foot buckling Diamond buckling of tank wall Settlements of ground	Uplifting	Base isolation
		Impact of floating roof to tank wall.	Overtopping Torch fire	Dissipative spacers between roof and wall, TMD
Squat equipment placed on short columns	Spherical tanks	Collapse of structure due to shear failure of columns		Dissipative bracings Base isolation Dissipative coupling
	Process Furnaces	Collapse of structure due to shear failure of columns	Leakage from pipes;	Base isolation
		Collapse of the chimney Detachment of internal pipes	Increase of temperature of Furnace wall	Dissipative bracings
		Detachment of the internal refractory material		TMD
	Cryogenic tanks	Collapse of structure due to shear failure of columns		Base isolation
Piping systems and support structure	Steel or R.C. frames	Collapse for excessive stresses	Damages to supported equipment (pipes, tanks,...)	Dissipative bracings Dissipative coupling Non-conventional TMD

Possible techniques...

Seismic protection of Industrial Components

Passive Control Systems

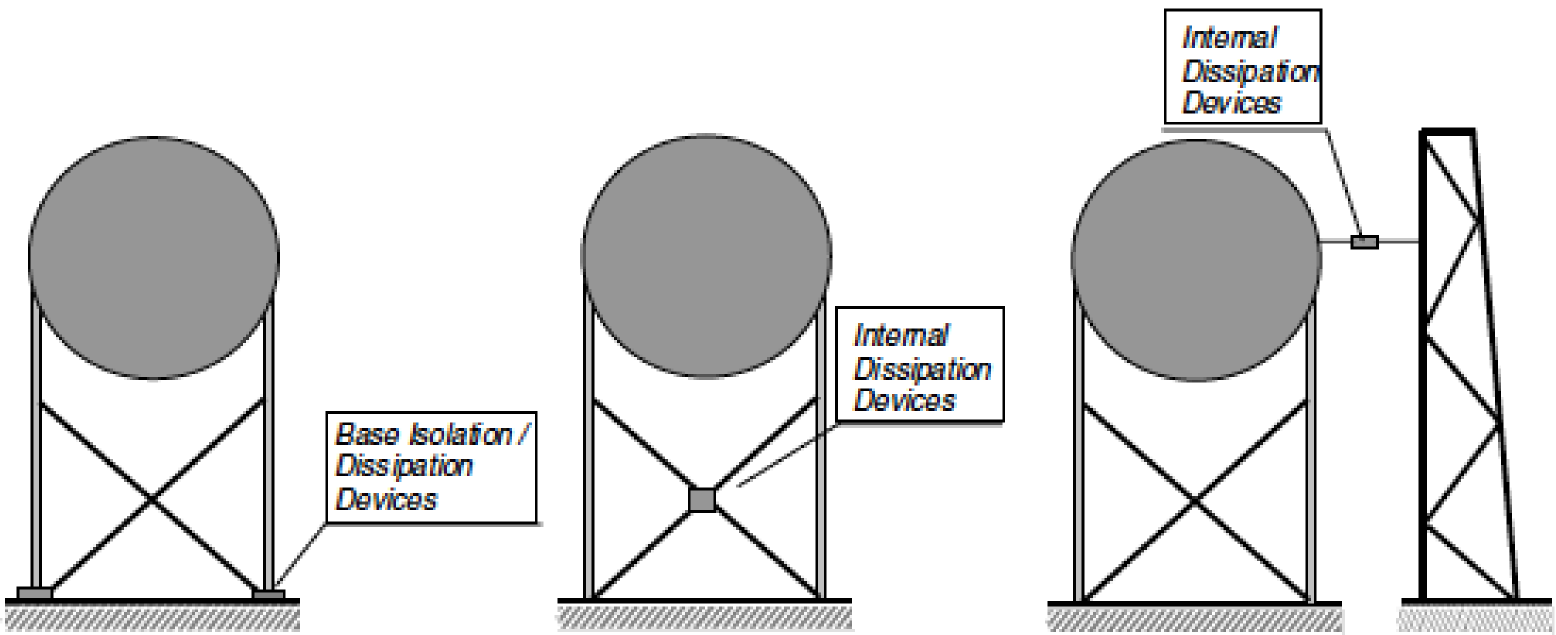
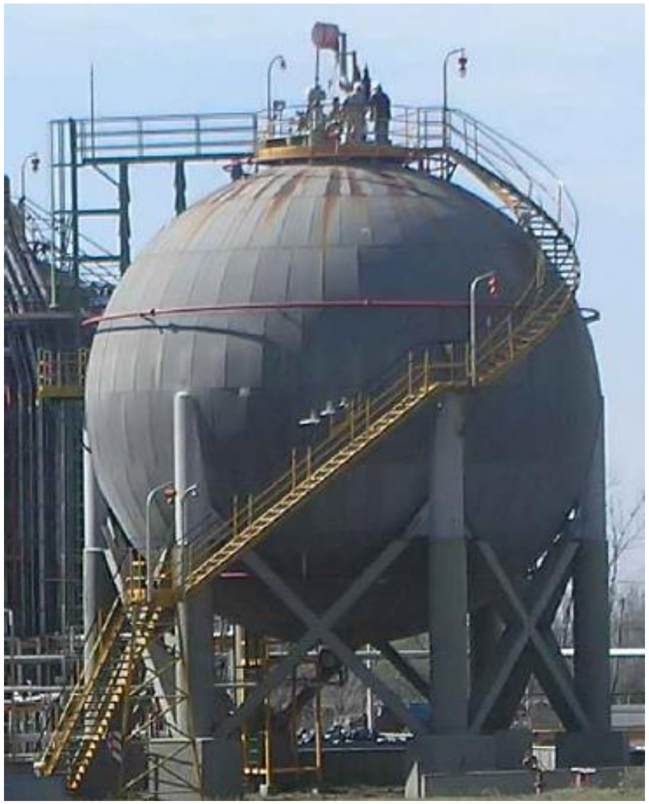


Figure 8: Different passive protection systems

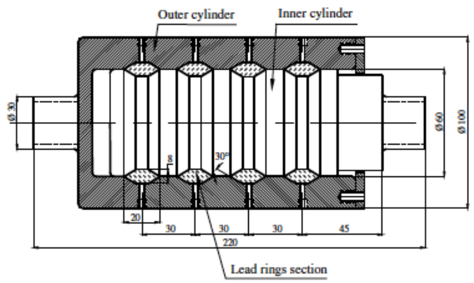
POSSIBILI SISTEMI DI PROTEZIONE PASSIVA PER SERBATOI

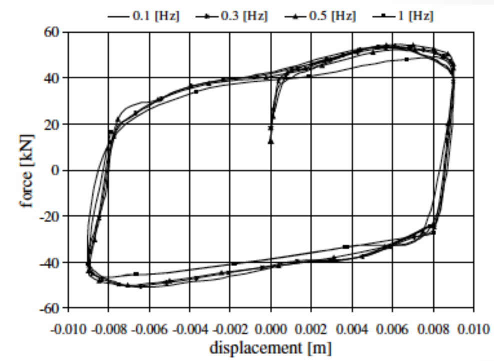
Passive Control Systems

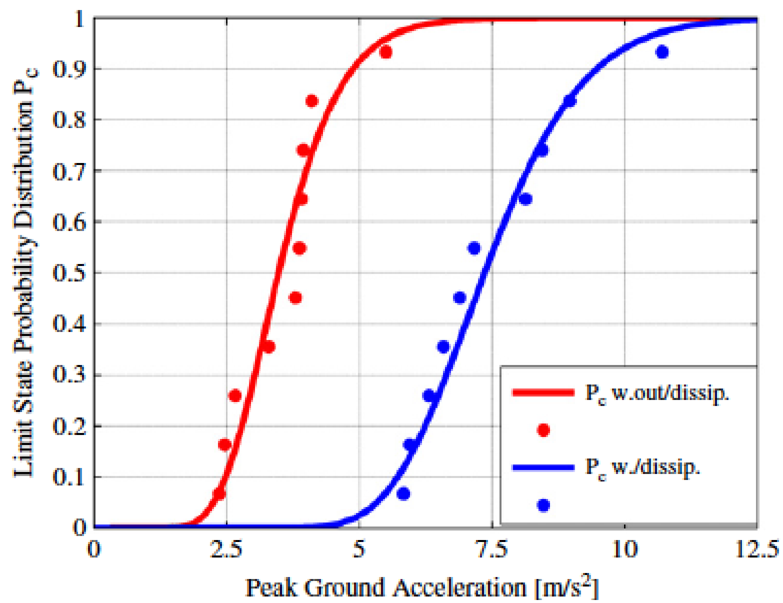
Dissipazione di energia (Curadelli 2011)



Controventamento dissipativo







Passive Control Systems

Dissipazione di energia (Malhotra 1998)

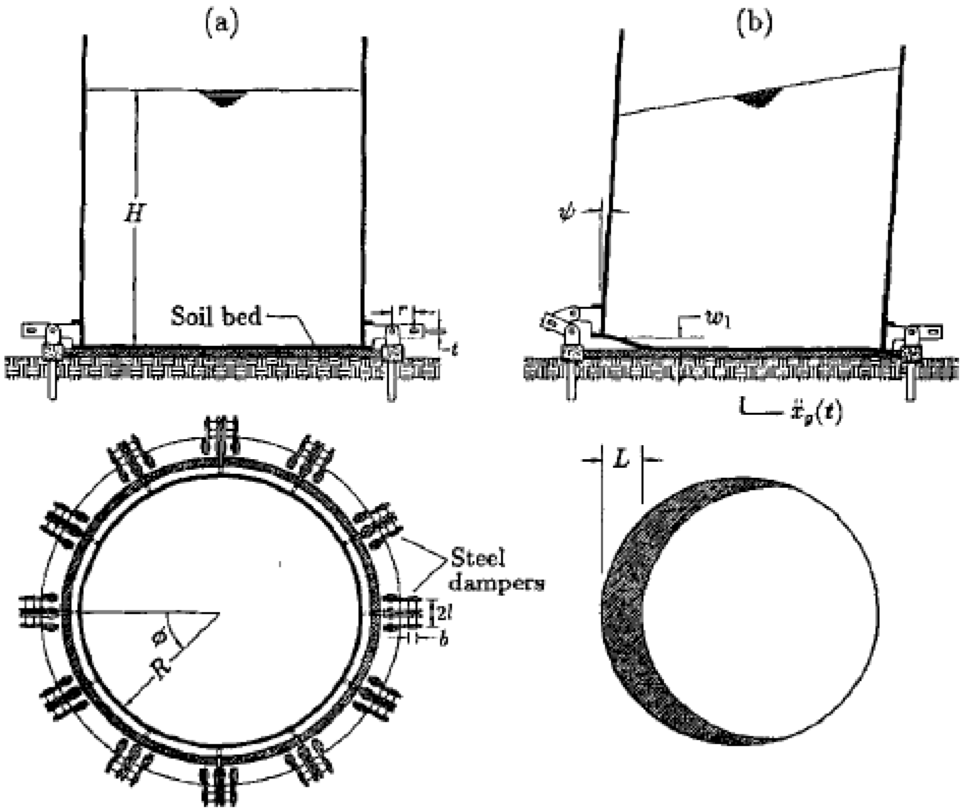
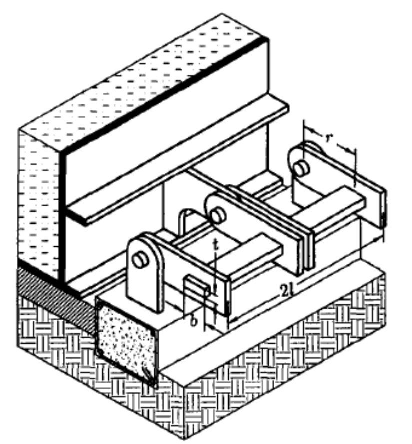
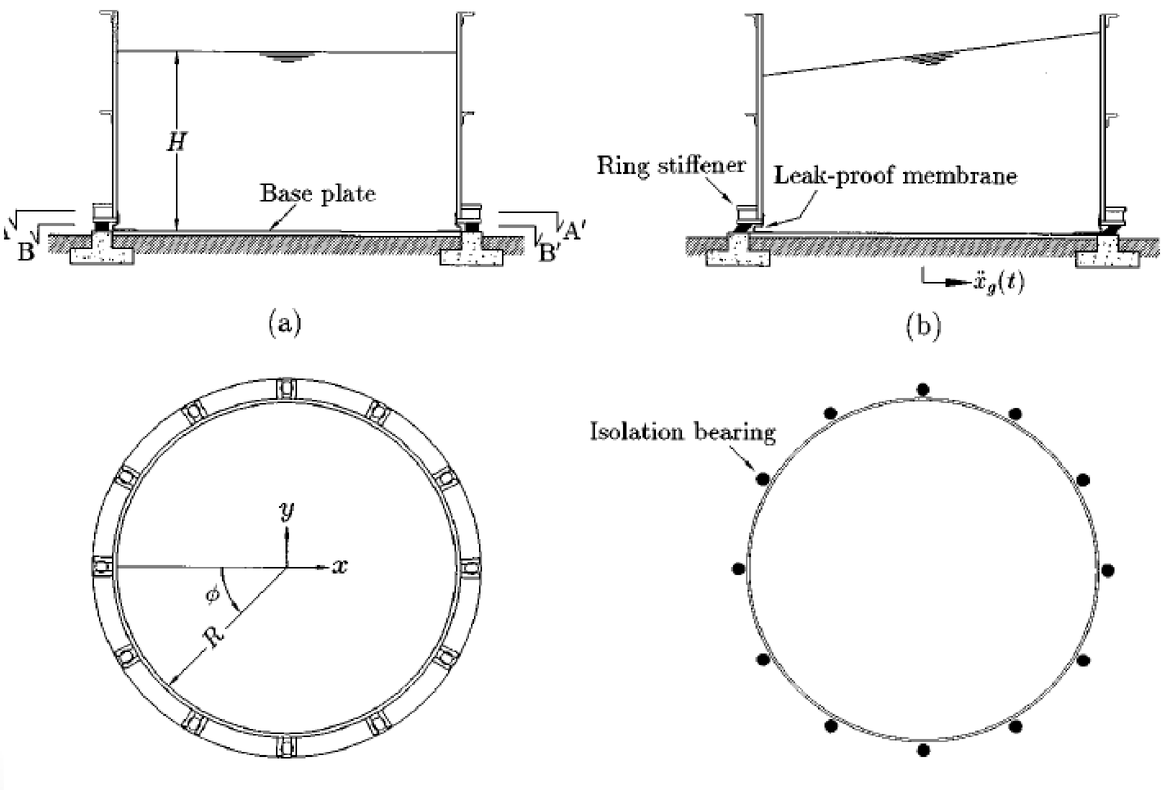


FIG. 1. Liquid-Storage Tank Anchored with Steel Hysteretic Dampers

N.B.
Questa soluzione sfrutta il fenomeno dell’uplift,i cui spostamenti rispetto al terreno vengono sfruttati per attivare un meccanismo di dissipazione ad hoc



Isolamento sismico (Malhotra 1997)



(a) (b)

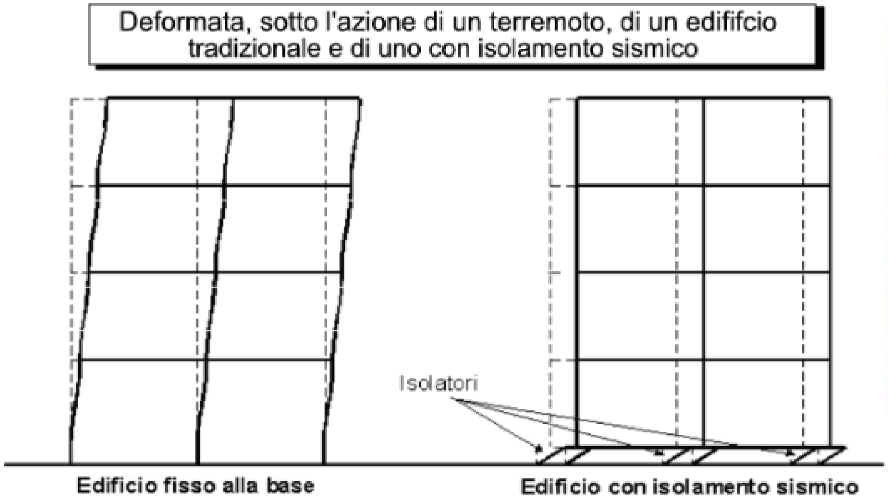
(c) Section A–A′ (d) Section B–B′

N.B.

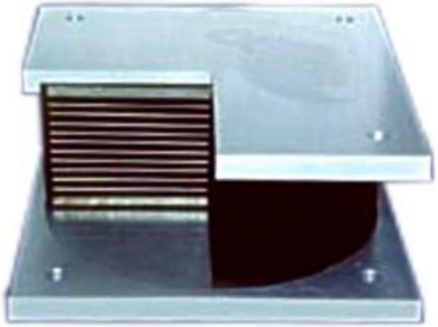
Questa soluzione ha il vantaggio di non dover realizzare una soletta rigida alla base

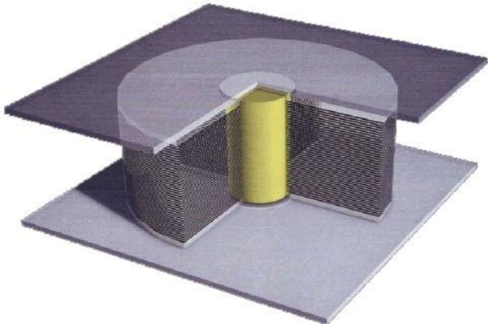
Seismic protection of Industrial Components

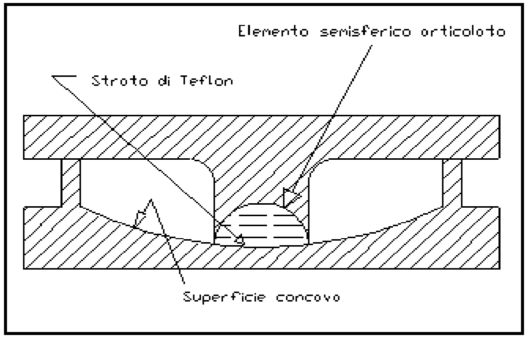
Base Isolation



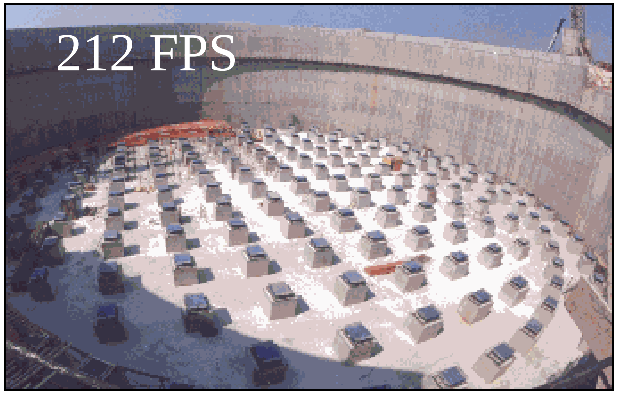
ISOLATORE ELASTOPLASTICO

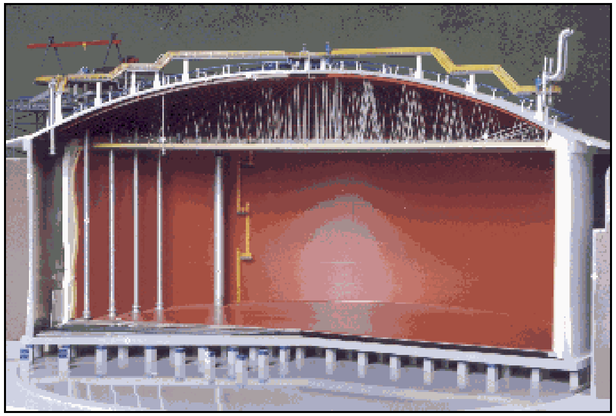


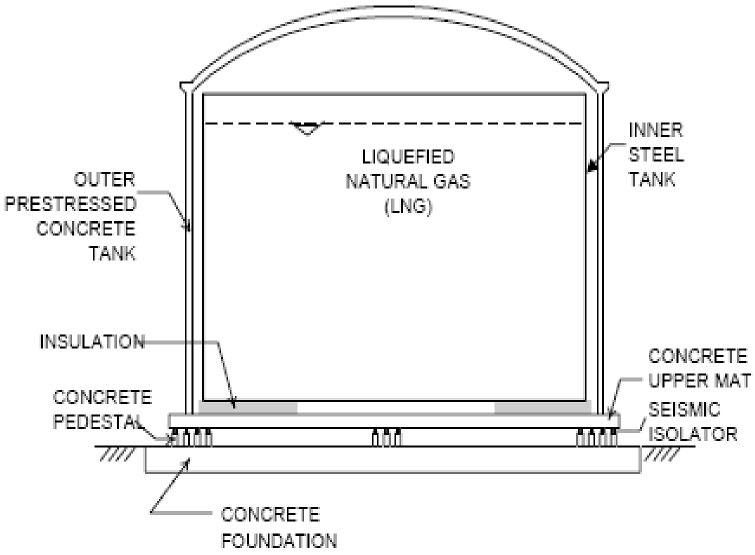




Base Isolation







Isolamento alla base di serbatoi LNG

Isolamento mediante FPS del serbatoio LNG di Revithoussa Island in Grecia

Seismic protection of Industrial Components

Base Isolation

Isolamento alla base di serbatoi LNG

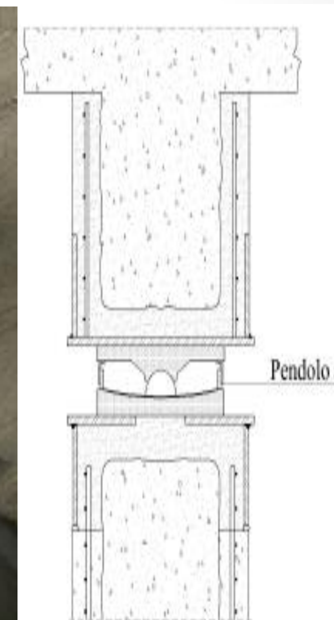
Isolamento mediante FPS del serbatoio LNG a Melchorita in Perù

Seismic protection of Industrial Components

Base Isolation

Seismic retrofitting of a steel tank using 26 HDRB isolators Switzerland

Seismic protection of Industrial Components
Base Isolation



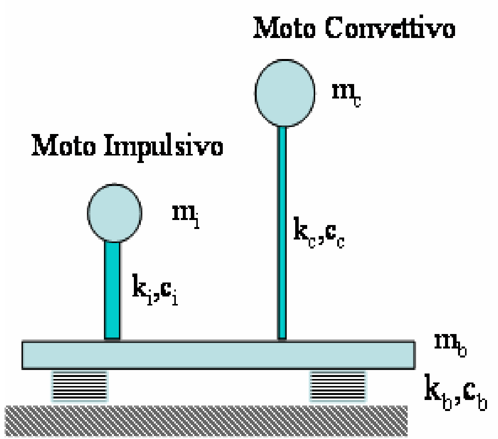
Seismic retrofitting of a steel tank using FPS
Petrolchimical pole of Siracusa
Priolo Gargallo (Sr) – Sicily

Seismic protection of Industrial Components
Base Isolation

Quali tipi di isolatori utilizzare?

Base Isolation

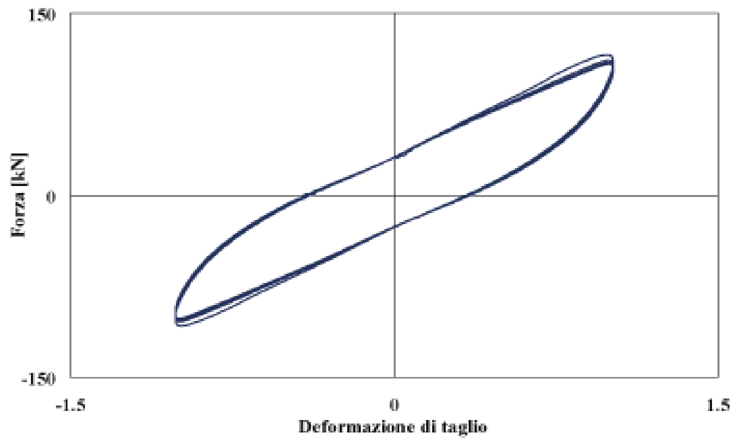
- Si può utilizzare il modello a pochi gradi di libertà
- Il comportamento non lineare dei dispositivi di isolamento può essere agevolmente implementato
- Per una progetto di prima approssimazione si può ipotizzare che la massa isolata sia solo quella impulsiva, essendo quella convettiva già naturalmente isolatata avendo un periodo molto elevato.
- Di conseguenza la rigidezza del sistema di isolamento può essere facilmente ricavata dalla relazione seguente



$$T_{iso} \approx 2\pi \sqrt{\frac{m_i + m_s + m_b + m_w}{k_{iso}}} = 2\pi \sqrt{\frac{m_{tot}}{k_{iso}}}$$

Periodo del serbatoio isolato

Base Isolation

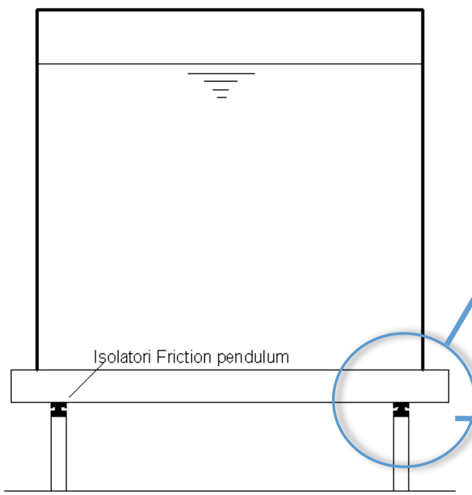


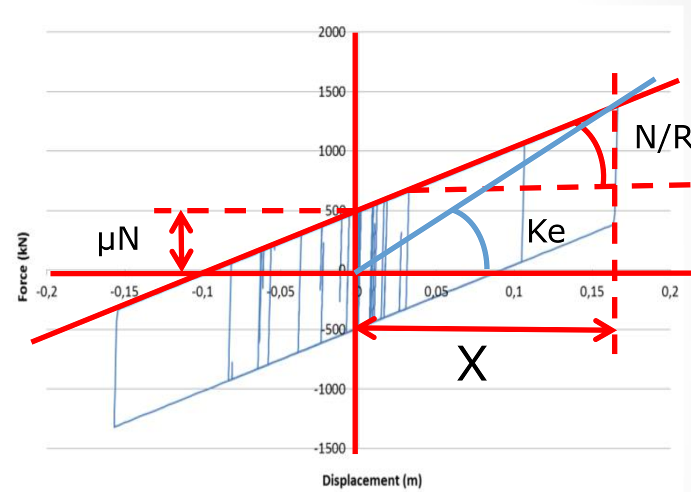
PROCEDURA DI PROGETTO:

1) Si ipotizza il periodo di isolamento Tiso
2) Individuata la massa da isolare si calcola la rigidezza Kiso
3) Ipotizzato uno smorzamento (10%) si valuta dallo spettro di risposta degli spostamenti, lo spostamento massimo dell'isolatore
4) Ipotizzando una deformazione del 100% si calcola l'altezza della gomma
5) Si determina il numero degli isolatori in maniera da rispettare le condizioni di sicurezza nei confronti dell'instabilità

Seismic protection of Industrial Components

Base Isolation





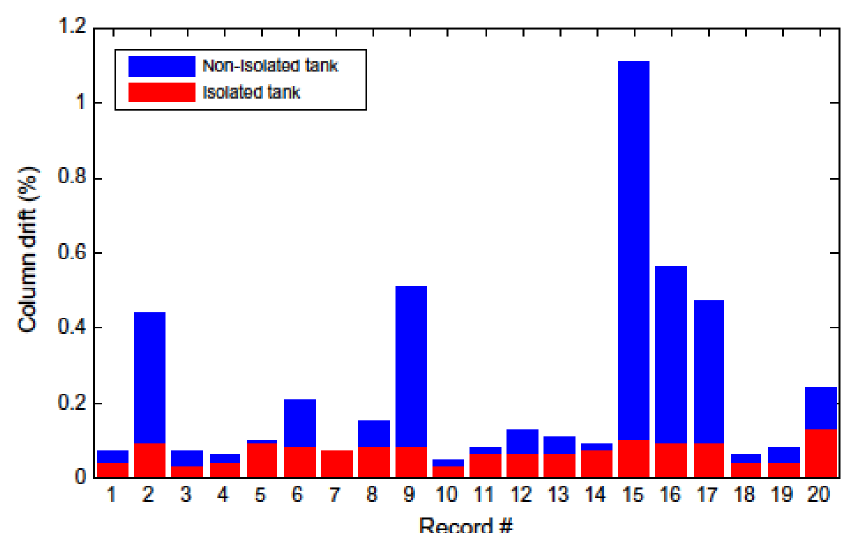
$$T_p = 2\pi\sqrt{\frac{m}{k_e}} = 2\pi\sqrt{\frac{m}{g\,m\,(\frac{1}{R}+\frac{\mu}{X})}} = 2\pi\sqrt{\frac{1}{g\,(\frac{1}{R}+\frac{\mu}{X})}}$$

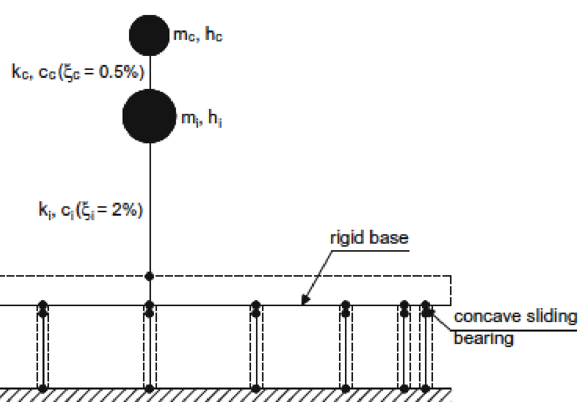
Vibration Period of base-isolated structure with FPS

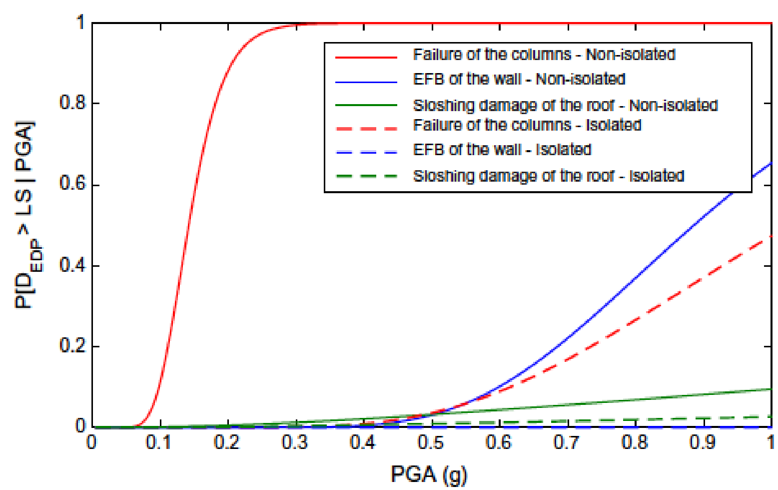
$$T_p = 2\pi\sqrt{\frac{m}{k_e}} = 2\pi\sqrt{\frac{m_{imp}+m_{ss}+m_{iso}}{g\,m_{tot}\,(\frac{1}{R}+\frac{\mu}{X})}}$$

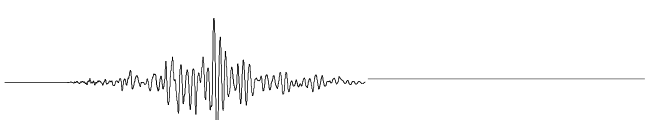
Vibration Period of base-isolated Tank with FPS

Seismic protection of Industrial Components
Base Isolation: Example









Conclusions (Riscrivere)

- The need to study carefully the earthquakes effects on industrial plants with major-accident hazards has been addressed.
- In particular, typical equipment and components of refineries were identified, their vulnerability was analyzed, both looking for into historical events, concerning damages caused by past earthquakes to several industrial plants and investigating the typology of the structural nature of the different components of a plant.
- This analysis allowed identifying the most critical elements both for their seismic vulnerability and for the consequences of their damage state
- Vulnerability assessment methods based on fragility analysis of storage tanks has been illustrated

Conclusions

- The application of Fragility analysis has been illustrated on an emblematic case study of an actually collapsed LNG tanks
- Nonlinear time history and probability response analyses using a 3D model have been presented.
- Cloud and IDA approaches for data collection and statistically appropriate methods for fragility function fitting were discussed.
- The Cloud Method involves the non-linear analysis of the structure subjected to a set of un-scaled ground motion time-histories.
- IDA can be quite time-consuming as the non-linear dynamic analyses using scaled ground motion time-histories for increasing levels of ground motion intensity.

Conclusions

- Supporting columns were collapsed by pure-shear and investigated by drift ratio at shear failure.
- Tank shell wall buckling and liquid sloshing also investigated and compared with the capacities.
- It was evidenced that failure in support structure columns is the most influencing one. This is fully in accordance with the real collapse mode.
- The application of the base isolation technique appears particularly effective in reducing the impulsive pressure on the tank wall and then of the corresponding base shear.
- An application on elevated tanks demonstrated this assertion

Thank you very much for your attention

Questions?

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