XXVI CONGRESSO DEI TECNICI DELL'ACCIAIO
Venezia, 28-30 Settembre 2017

PERFORMACE OF A FULL SCALE LNG PLANT IN A SEISMIC HIGH-PRONE AREA

Pedot M.*, Bursi O.S.**, Di Filippo R.**, La Salandra V.**, Reza Md S.***

* Silesian University of Technology
** University of Trento
*** Ingenieurgesellschaft Dr.-Ing. Fischbach Mbh - IGF

ACKNOLEDGMENTS

The authors gratefully acknowledge the financial support from the European Union through:

- the INDUSE-2-SAFETY project (Grant number: RFS-PR-13056);
- the XP-RESILIENCE project (Grant number: 721816);

TABLE OF CONTENTS

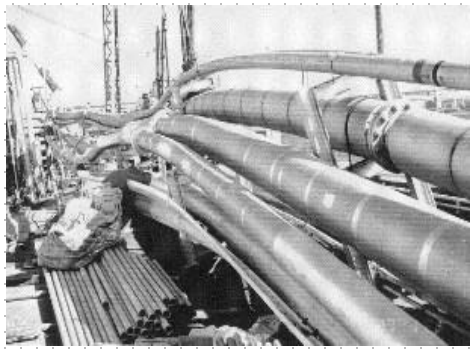
SEISMIC RISKS IN PETROCHEMICAL PIPING SYSTEMS

Piping Systems and Components suffer severe damages under earthquakes.

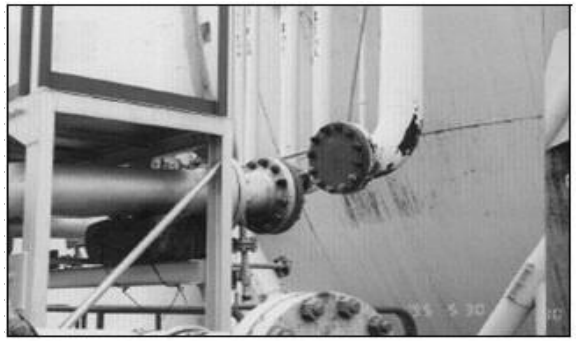
Consequences:

- Casualties;
- Loss of assets;
- Environmental Pollution;
- …

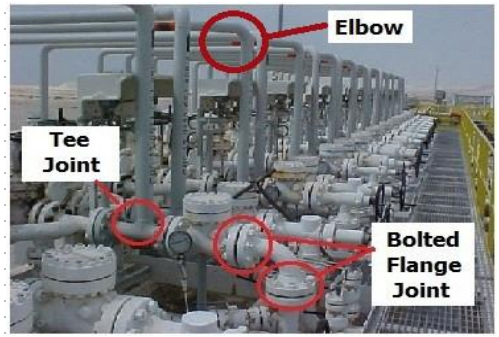
Refinery Conflagration
Kocaeli Earthquake, Turkey, 1999



Pipeline failure
Kobe Earthquake, Japan. 1995



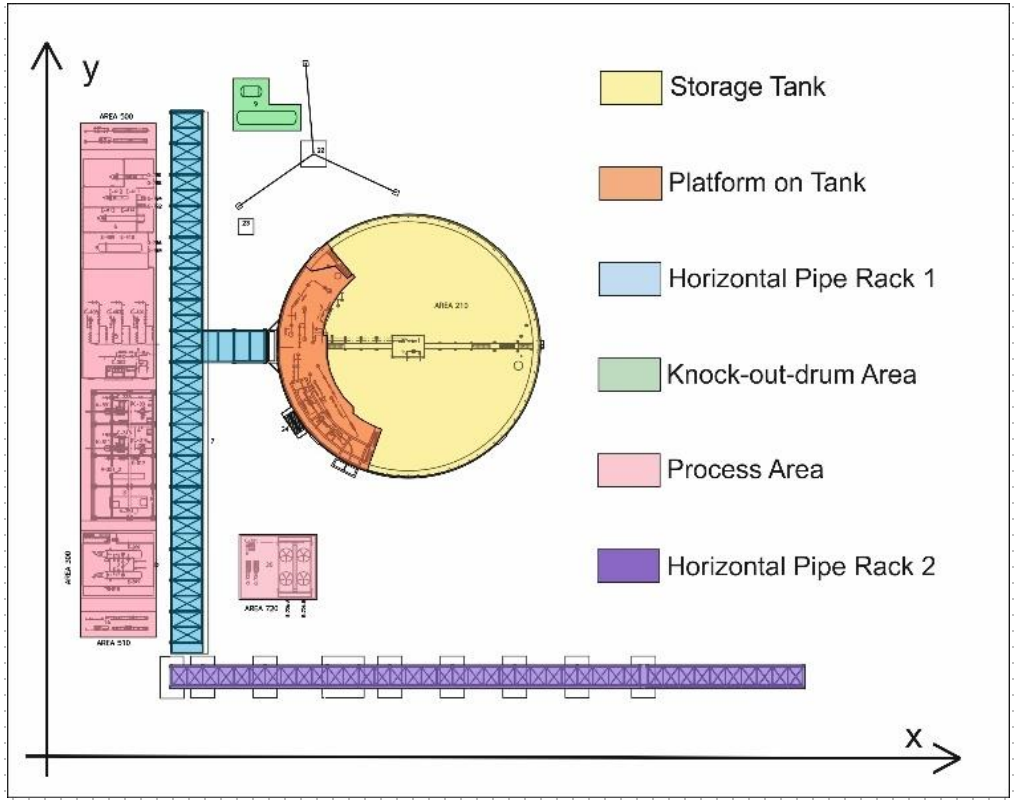
Bolted flange joint failure
Kobe Earthquake, Japan. 1995

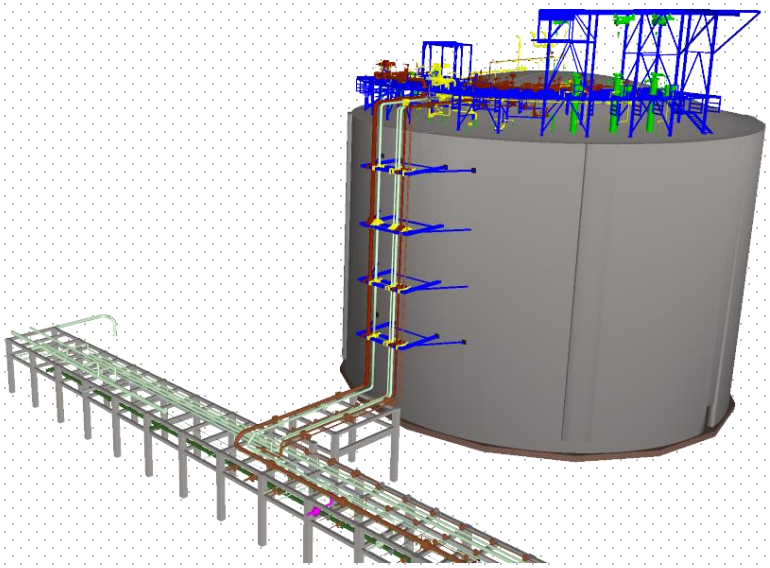


Components that might experience Loss of Containment (LoC)

LIQUIFIED NATURAL GAS (LNG) PLANT

THE LNG PLANT – CASE STUDY #2



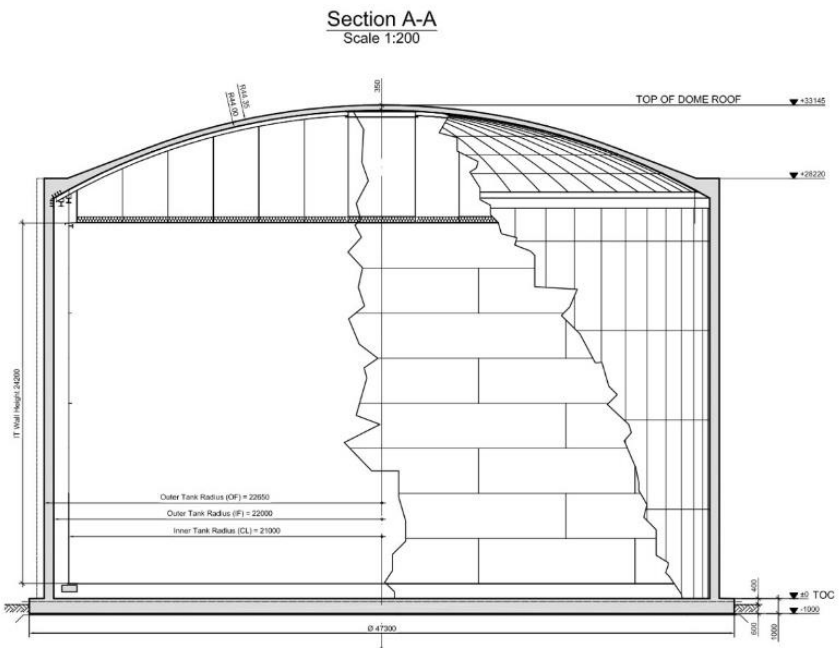


- Case Study #2 → Regassification plant
  - Storage tank for ethylene
  - Piping system
  - Supporting structures for pipings
    - Concrete structure
    - Steel platform
  - Process Area for Ethylene:
    - Knock-out-Drum Area

Preliminary Assumption:

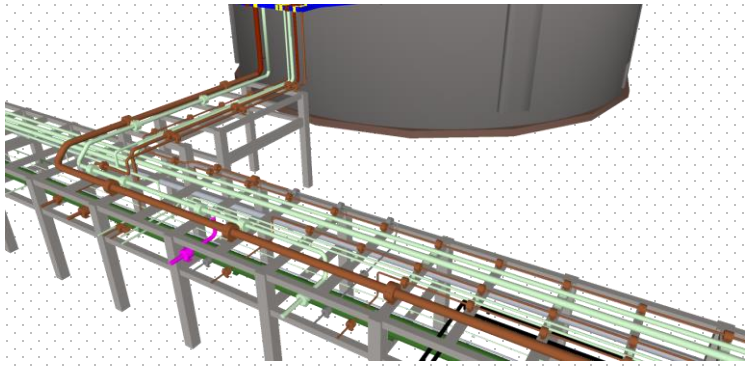
The plant is located in a seismic high-prone area: Priolo Gargallo – Sicily

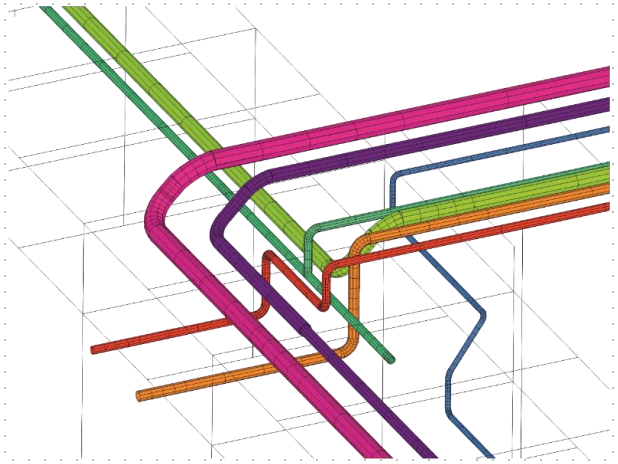
THE LNG PLANT - SUBSTRUCTURES



MAIN TANK

Capacity: 50000 m^3 - Ethilene stored at -102°C;
Concrete Outside Layer (C30/37):
Diameter: 49 m;
Thickness: 0.65 m;
Height: 38 m at the base of the dome;
High Resilience Steel X8Ni9 Inside Layer:
Diameter: 46 m;
Concrete Dome:
Height: 44 m;
Thickness: 0.85 – 0.35 m;

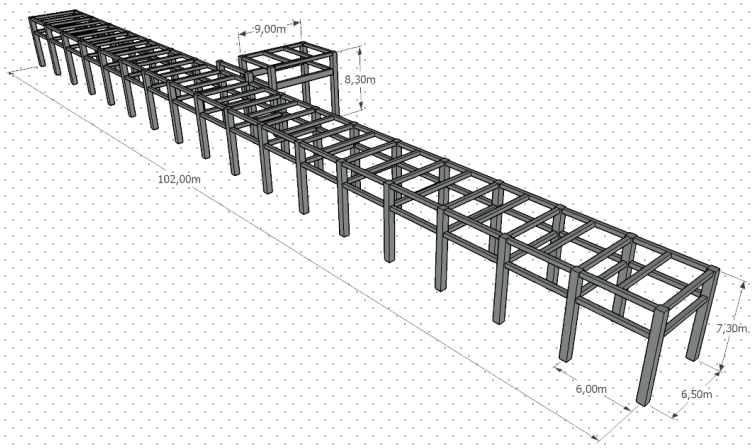


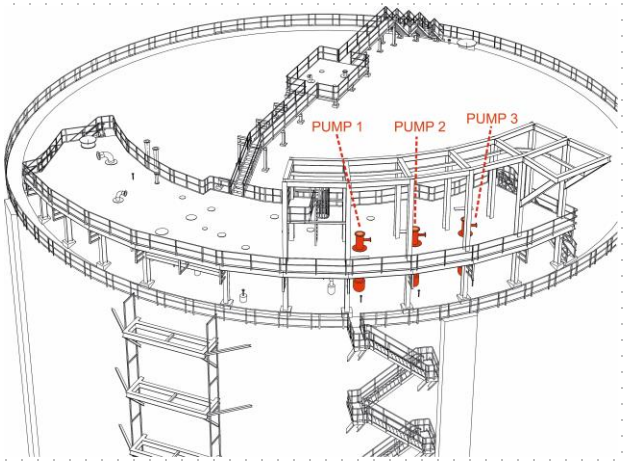


PIPING SYSTEM

Stainless Steel: A358/A403
Diameters:
4” ÷ 16”
Connections:
Welded;
Bolted flange joints;

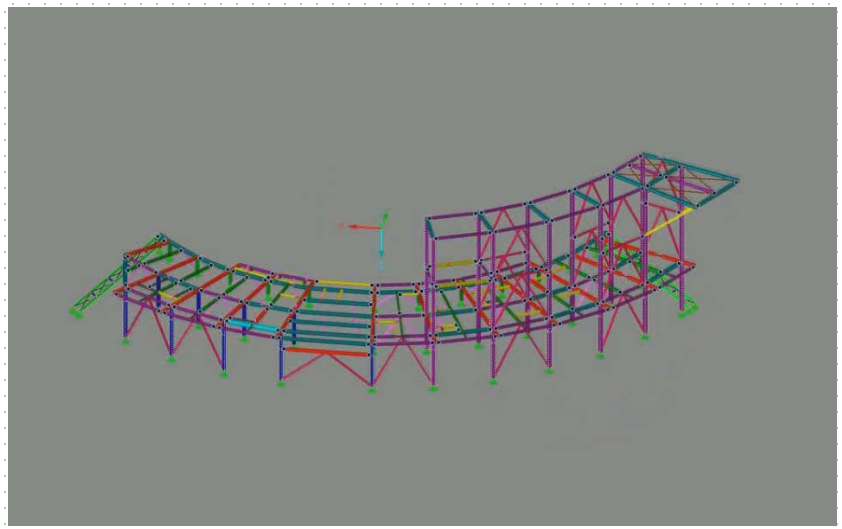
THE LNG PLANT - SUBSTRUCTURES





CONCRETE SUPPORT STRUCTURE

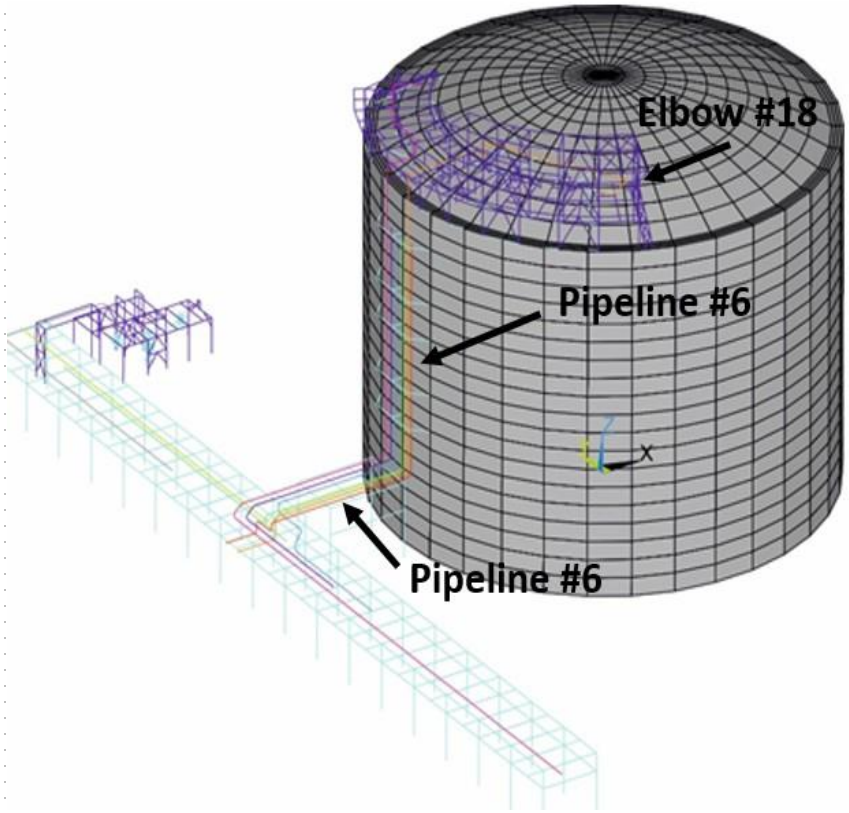
Concrete Structure (C40/50):
Dimensions: 102 x 6,5 x 7,3 m;
Columns Section:
600 x 600 mm;
Beam sections:
350 x 350 mm;
350 x 700 mm;



STEEL PLATFORM

Steel Structure (S235):
IPE and HE B Profiles
Total Height: 10 m

THE LNG PLANT - ANSYS FE MODEL

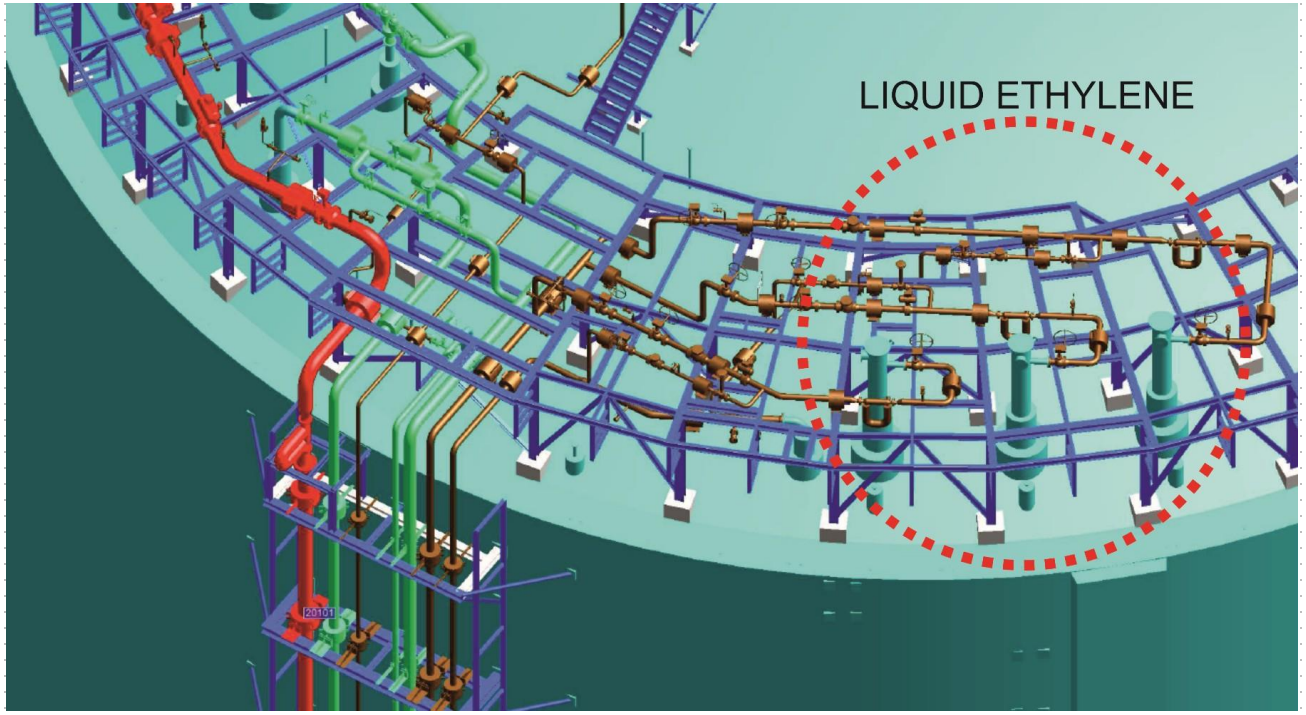


~ = 20,000 degrees of freedom

- 1338 elements BEAM4;
- 84 elements LINK180;
- 159 elements PIPE289;
- 95 elements ELBOW290;
- 1122 elements SHELL181

It takes 3 days to run 1 seismic analysis

LEAKAGE AND FAILURE CASES - FLANGES

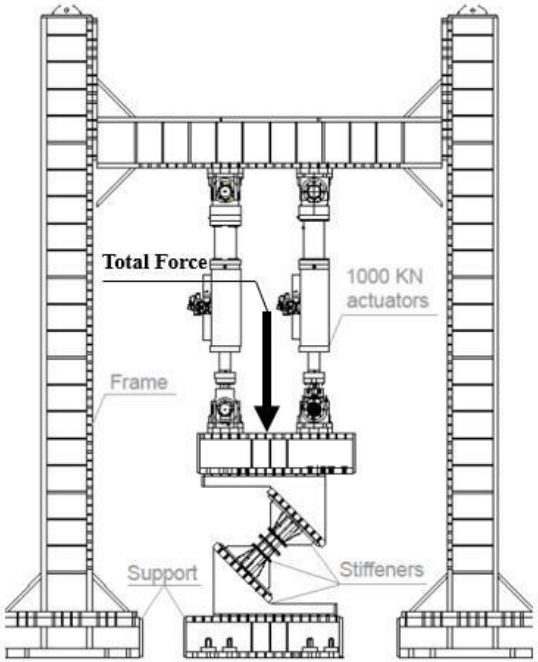


The flanges in the pipelines (otherwise welded) are located only in the attachments with pumps on top of the storage tank.

6” BFJs → Weld Neck Flanges CL300

Experimental mechanical characterization

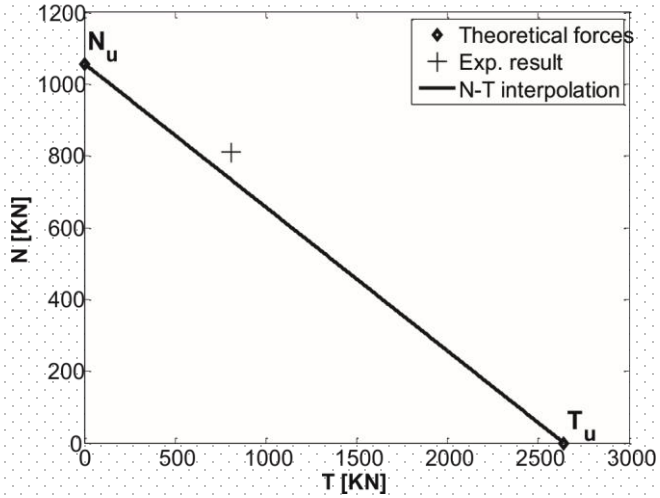
LEAKAGE AND FAILURE CASES - FLANGES



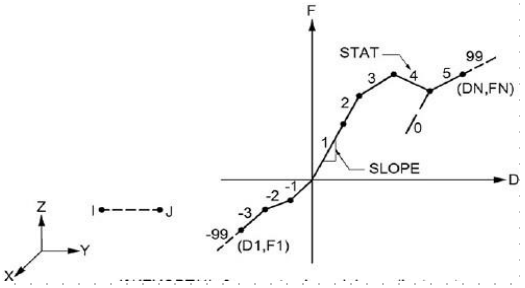
Experimental setup for tests on 8'' BFJ

- Axial stiffness from UNI EN 1591-1
- Shear stiffness according to experimental tests
- A predictive model, based on experimental tests was used to evaluate leakage forces.

*La Salandra V.; di Filippo R.; Bursi O. S.; Paolacci F.; Alessandri S., 2016. Cyclic Response of Enhanced Bolted Flange Joints for Piping Systems. Proceedings of the ASME 2016 PVP2016, Vancouver, British Columbia, Canada, July 17-21, 2016.

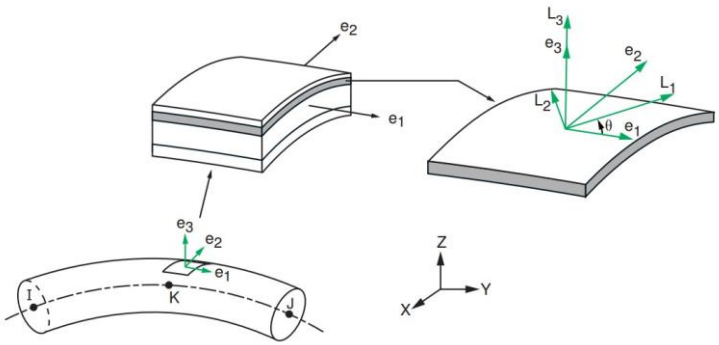


	6'' Weld Neck Flange CL300
Axial stiffness [kN/mm]	14400
Shear stiffness [kN/mm]	1270
Axial leakage force [kN]	939
Shear leakage force [kN]	2228

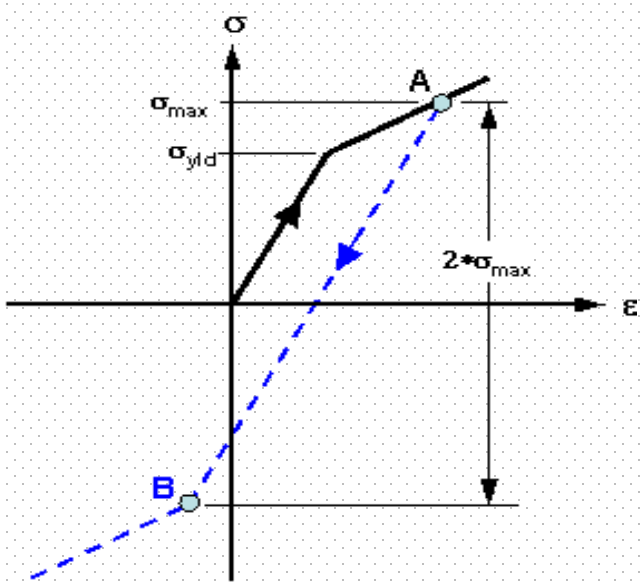


We adopted the **non-linear COMBIN39** spring element of ANSYS software. With regard to the compressive behavior, we made the assumption of a significantly higher stiffness.

LEAKAGE AND FAILURE CASES - ELBOWS



Elbows were modelled with Ansys ELBOW290 elements which are based on a 3-nodes structure. External walls are modeled with elements SHELL181.



In preliminary analyses we found that the stress levels in elbows were above the yielding point. For this reason the nonlinear yielding behavior of the piping steel was modeled in ANSYS through kinematic hardening. The model was based on experimental data.

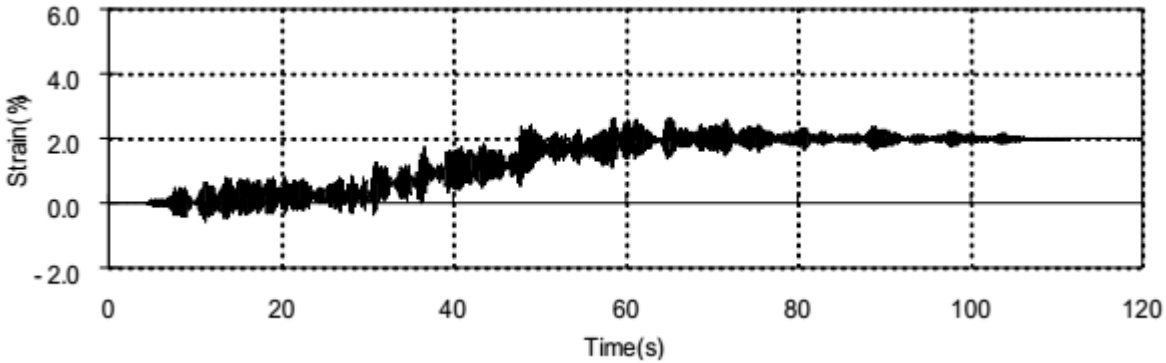
Stainless Steel ASTM A403 WP304	
T = -80°	T = RT
σ_{yld} = 366 MPa	σ_{yld} = 277 Mpa
ε_{yld} = 1.74%	ε_{yld} = 1.36 %

LEAKAGE AND FAILURE CASES - ELBOWS

Leakage Limit State – HOOP TENSILE STRAIN

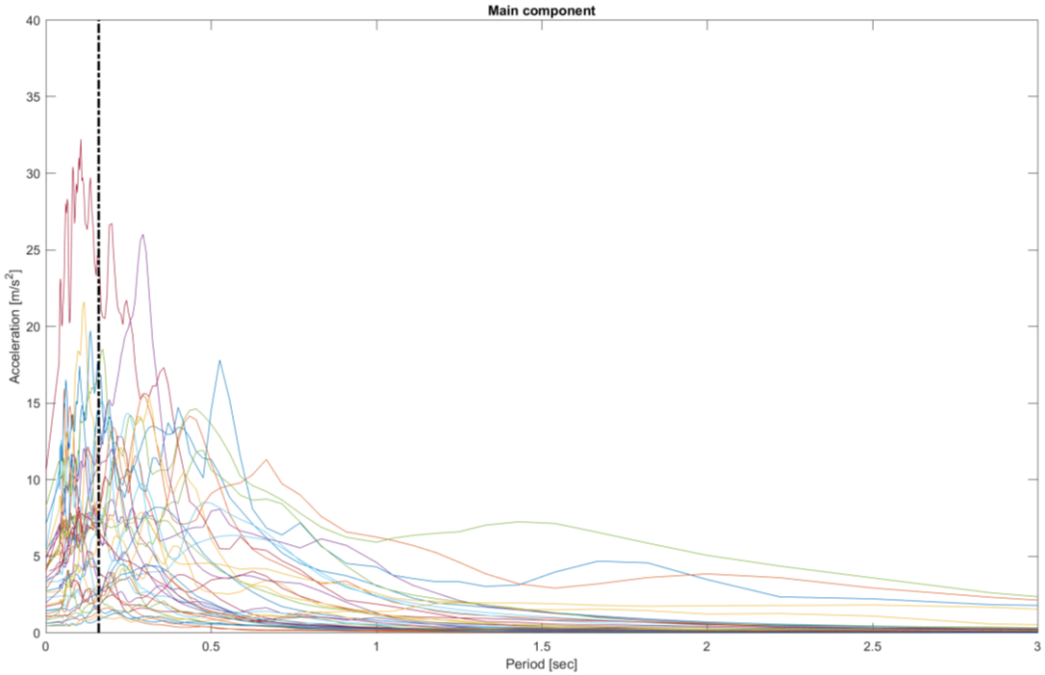
As shown in results from JNES-NUPEC* (2008), the elbow strain level could predict a leakage event. **In particular a hoop strain equal to 2% was found to be the onset of leakage.**

**Seismic Analysis of Large-Scale Piping Systems for the JNES-NUPEC Ultimate Strength Piping Test Program (2008)*



PROBABILISTIC SEISMIC DEMAND ANALYSIS

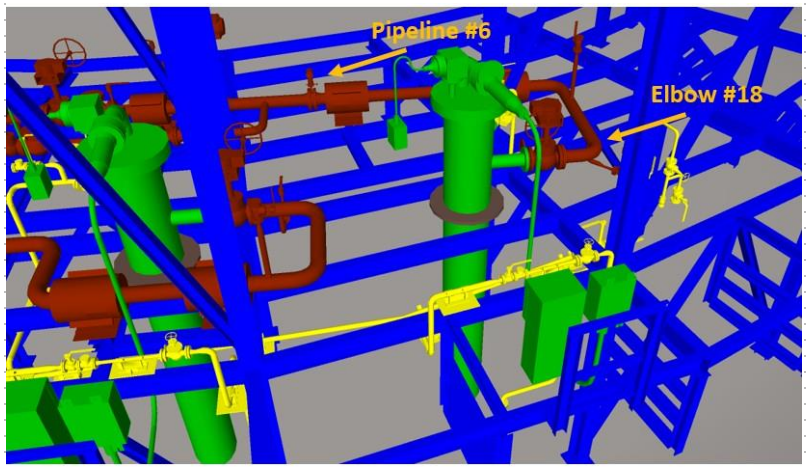
- Performed with Cloud Analysis Method;
- The $S_a(T)$ was chosen as Intensity Measure (IMs). The period of the spectral acceleration was set according to the main vibrational mode of the LNG tank, i.e. T=0.16s.
- Suite of 36 natural ground motions selected from European Strong Motion Database (ESM) with different values of magnitude Mw and PGA



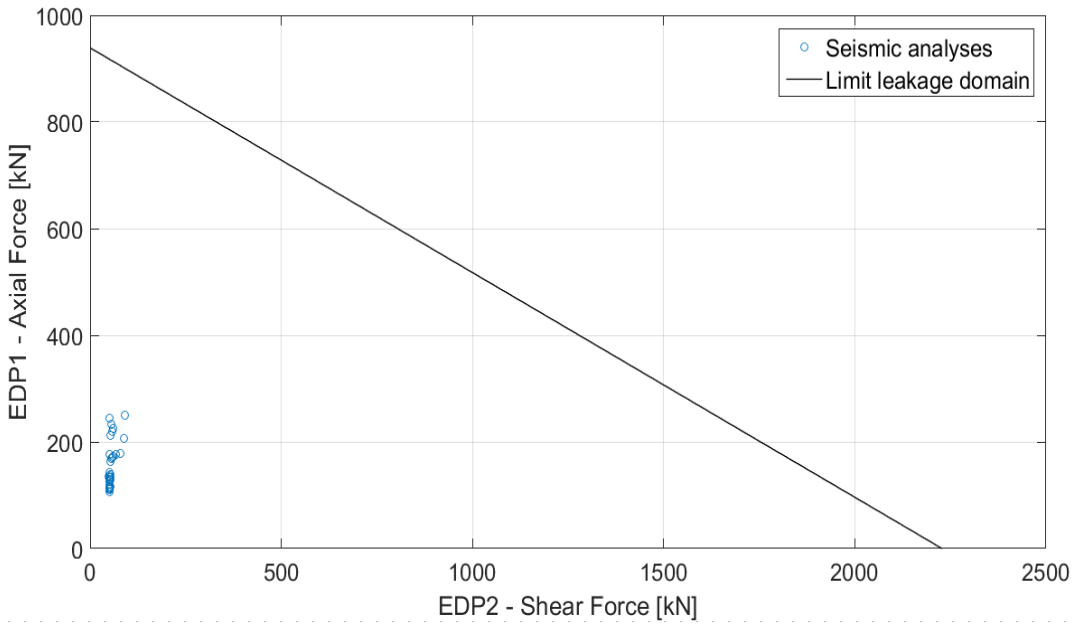
We applied the 3 components (X, Y, and Z direction) of each accelerograms together. Actual direction in model analysis were chosen in order to obtain the most demanding conditions

PROBABILISTIC SEISMIC DEMAND ANALYSIS

Results for 6” Bolted Flange Joints – Tank Platform



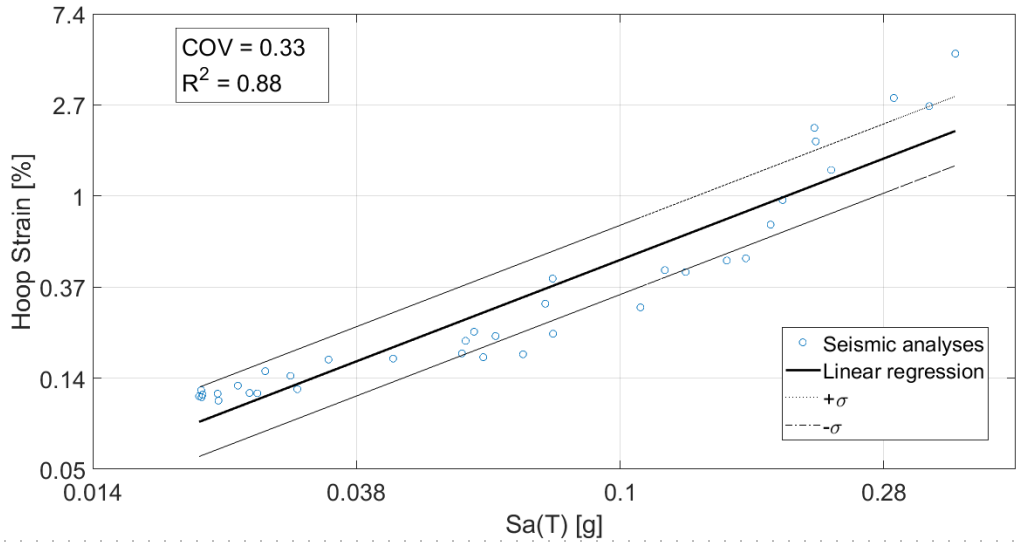
BFJ connecting pumps on top of the tank and pipeline #6

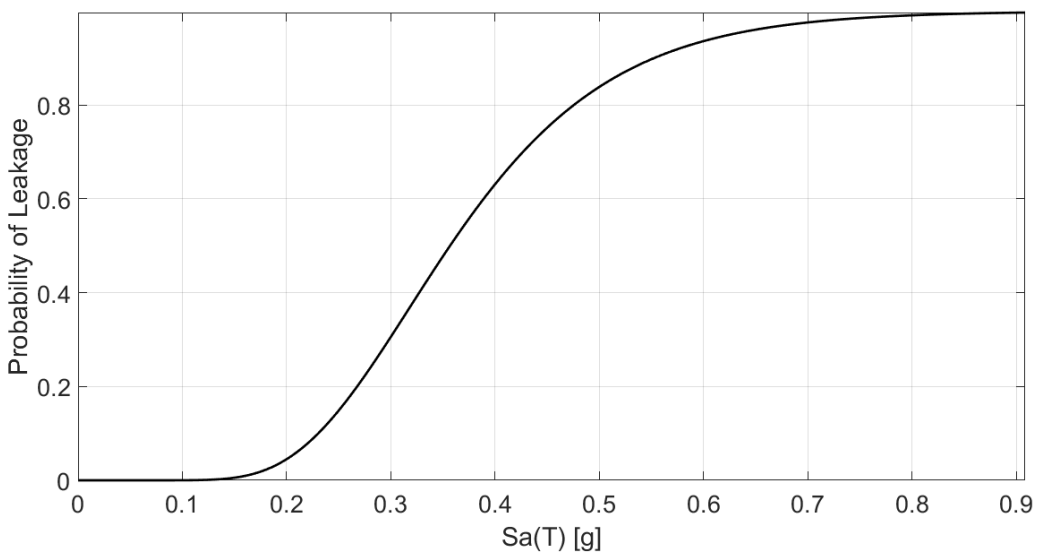


It is possible to conclude that flanges are relatively safe against the seismic action

PROBABILISTIC SEISMIC DEMAND ANALYSIS

Results for Elbow #18 – Tank Platform





Probability of Leakage over the reference life (100 years)

Hazard Curve of the high-seismic site of Priolo Gargallo (Sicily)

$$P(edp) = \int_{im} P(EDP > edp|im)|d\lambda(im)|$$

$$P_{leakage} = 1.4 \cdot 10^{-3}$$

CONCLUSIONS

- Bolted flange joints are relatively safe under seismic action;
- Elbows exhibit a significant degree of vulnerability: need for correct pipework design in LNG plants to withstand earthquakes, especially for piping components located on top of tanks.

$P_{leakage} = 1.4 \cdot 10^{-3}$ → EN 1990

→ $7.2 \cdot 10^{-5}$ Ultimate limit state

→ $6.7 \cdot 10^{-2}$ Serviceability limit state

- Maximum tensile hoop strain represents a suitable Demand Parameter;
- Fragility can be expressed as a function of Spectral Acceleration Sa(T);

THANK YOU FOR YOUR ATTENTION.