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


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SEISMIC RISKS IN PETROCHEMICAL PIPING SYSTEMS

Piping Systems and Components suffer severe damages under earthquakes.

Consequences:
- Casualties;
- Loss of assets;
- Environmental Pollution;
- ...

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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
• 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 m³ - Ethylene 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
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
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.


<table>
<thead>
<tr>
<th>6&quot; Weld Neck Flange CL300</th>
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<tr>
<td>Axial stiffness [kN/mm]</td>
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<tr>
<td>Shear stiffness [kN/mm]</td>
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<tr>
<td>Axial leakage force [kN]</td>
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<td>Shear leakage force [kN]</td>
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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.
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.

<table>
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<tr>
<th>Stainless Steel ASTM A403 WP304</th>
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<tr>
<td>$T = -80^\circ$</td>
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<tr>
<td>$\sigma_{yld} = 366$ MPa</td>
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<tr>
<td>$\varepsilon_{yld} = 1.74%$</td>
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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)
PROBABILITY 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.
It is possible to conclude that flanges are relatively safe against the seismic action.
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.

\[ P_{\text{leakage}} = 1.4 \times 10^{-3} \rightarrow \text{EN 1990} \]

- Maximum tensile hoop strain represents a suitable Demand Parameter;

- Fragility can be expressed as a function of Spectral Acceleration \( Sa(T) \);

7.2 \cdot 10^{-5} \quad \text{Ultimate limit state}

6.7 \cdot 10^{-2} \quad \text{Serviceability limit state}
THANK YOU FOR YOUR ATTENTION.