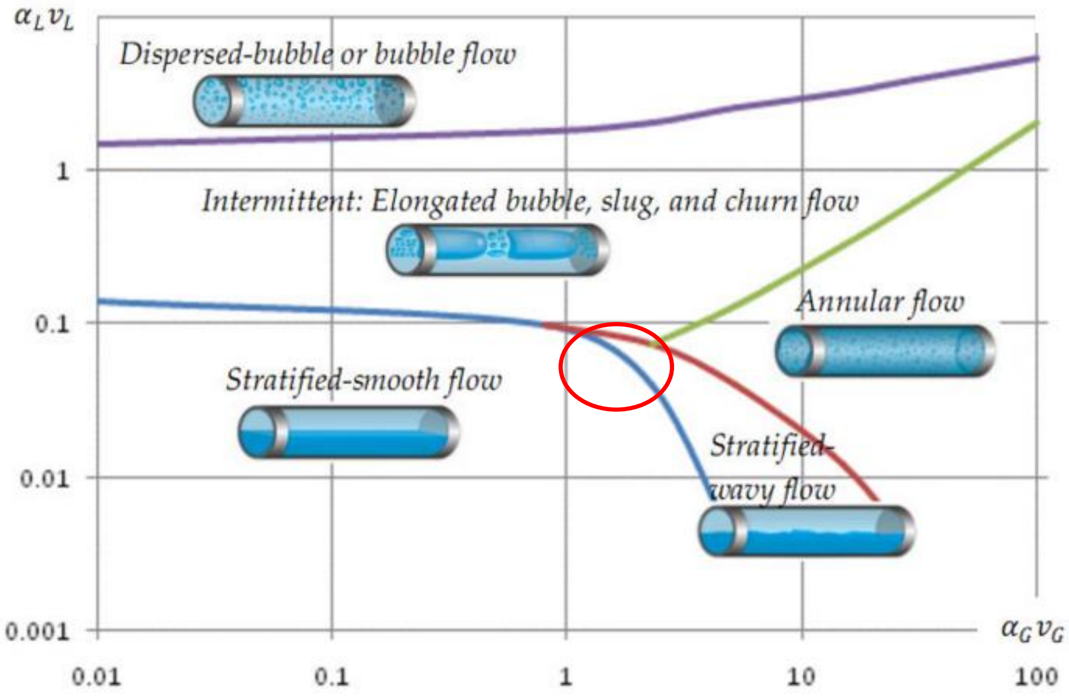
# Sensitivity Study of Slug-Induced Fatigue in Flow Line Spools

Loïc ANCIAN
VIBRATEC

# HYDRODYNAMIC SLUGGING

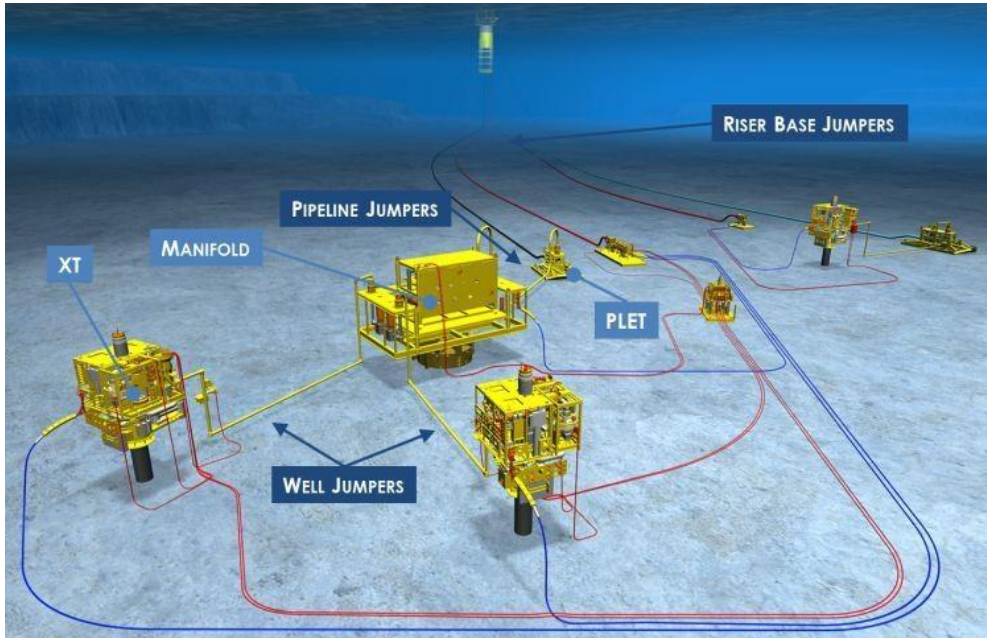
- Two phase intermittent flow
- Passage of sequences of liquid slugs alternating with sections of separated flow with long bubbles.
- Challenge: estimate piping system fatigue life




# SAMPLE IDEALISED SLUG DATA SET FOR FATIGUE CALCULATIONS

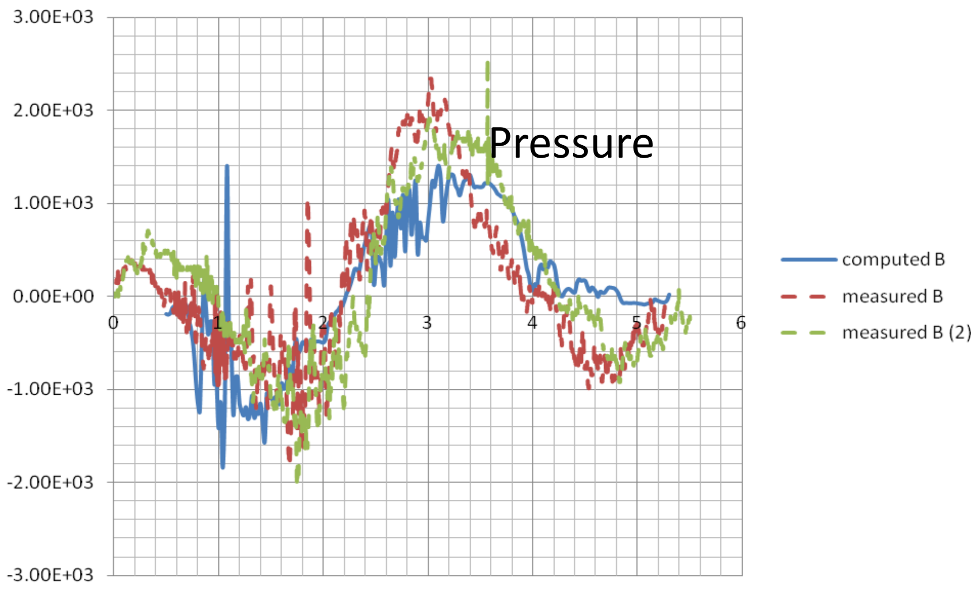
| Parameter | | Unit | Slug 1 | Slug 2 | Slug 3 | Slug 4 | Slug 5 |
|---|---|---|---|---|---|---|---|
| Liquid Slug Length | Range | [m] | 0 - 25 | 25 - 75 | 75 - 100 | 100 - 125 | 125 - 200 |
| | Base Case | [m] | 20 | 35 | 85 | 110 | 140 |
| Slug Pocket Length | Min | [m] | 25 | 30 | 40 | 50 | 45 |
| | Average[2] | [m] | 175 | 220 | 155 | 185 | 150 |
| | Max | [m] | 325 | 410 | 270 | 320 | 255 |
| Slug Unit Length | Min | [m] | 50 | 60 | 105 | 155 | 180 |
| | Average[2] | [m] | 195 | 255 | 240 | 295 | 290 |
| | Max | [m] | 340 | 450 | 375 | 435 | 400 |
| Equivalent Liquid Density | Min | [kg/m$^3$] | 620 | 620 | 620 | 620 | 620 |
| | Average[2] | [kg/m$^3$] | 750 | 750 | 750 | 750 | 750 |
| | Max | [kg/m$^3$] | 880 | 880 | 880 | 880 | 880 |
| Equivalent Pocket Density | Min | [kg/m$^3$] | 210 | 210 | 210 | 210 | 210 |
| | Average[2] | [kg/m$^3$] | 300 | 300 | 300 | 300 | 300 |
| | Max | [kg/m$^3$] | 390 | 390 | 390 | 390 | 390 |
| Slug Unit Velocity | Min | [m/s] | 4.00 | 3.80 | 3.75 | 4.00 | 4.00 |
| | Average[2] | [m/s] | 4.50 | 4.65 | 4.25 | 4.50 | 4.75 |
| | Max | [m/s] | 5.00 | 5.50 | 4.75 | 5.00 | 5.50 |
| Mean Slug Frequency | | [Slugs/hr] | 55 | 60 | 35 | 25 | 25 |
| % Slugs in Group[1] | | % | 30% | 25% | 20% | 15% | 10% |

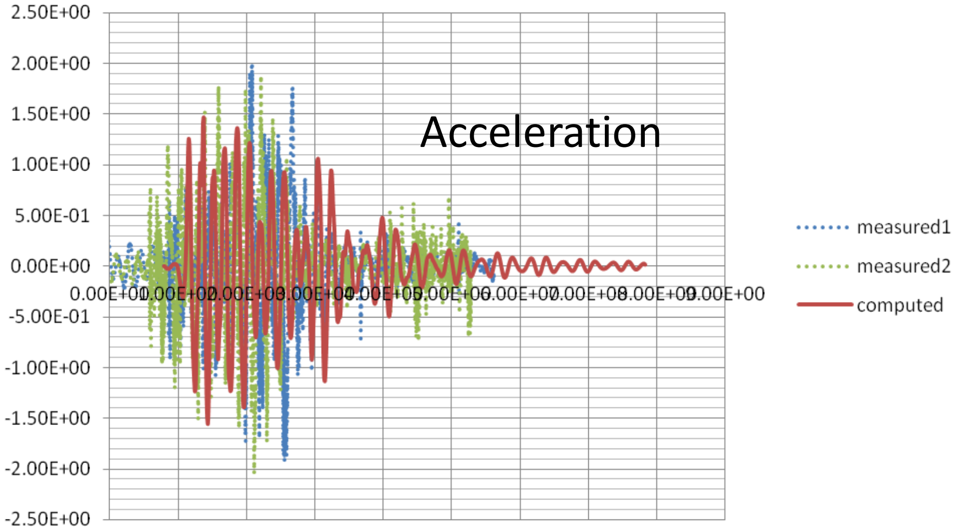
Notes
1. Supplementary occurrence data is required to perform fatigue damage calculation (see Table 4.2 for example.).
2. An alternative to average would be to provide most probable values.
3. Base case analyses are typically performed for parameter averages or most probable data.
4. All data provided in this table is based on sample data and created to illustrate data format only.

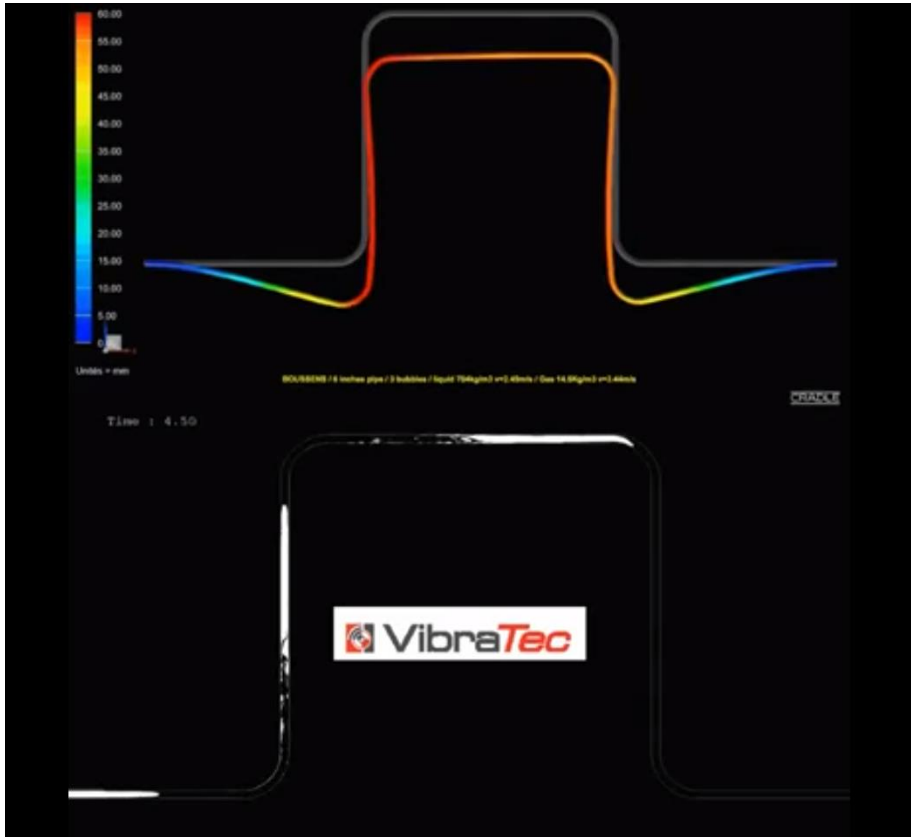



| Time | Slug 1 | Slug 2 | Slug 3 | Slug 4 | Slug 5 |
|---|---|---|---|---|---|
| Years 1 to 10 | 20% | 20% | 10% | 25% | 25% |
| Years 11 to 15 | --- | --- | --- | 50% | 50% |
| Years 16 to 20 | No Slug Flow Regime Predicted | | | | |

# PREVIOUS PROJECT RESULTS



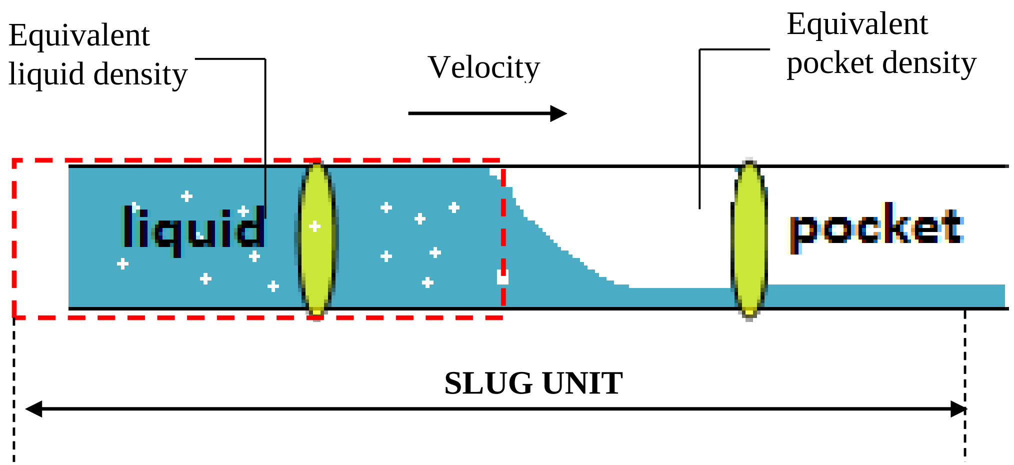
# FINITE ELEMENT MODELING

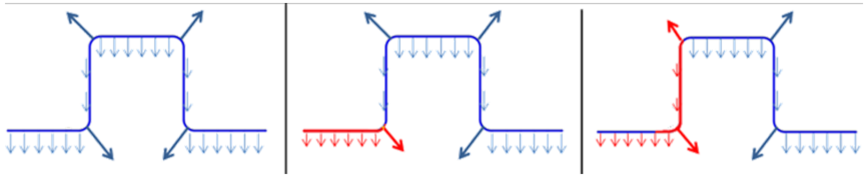
- Beam finite element model of the piping system

- Force loading history

  - weight variation as the bubble travels through the pipe

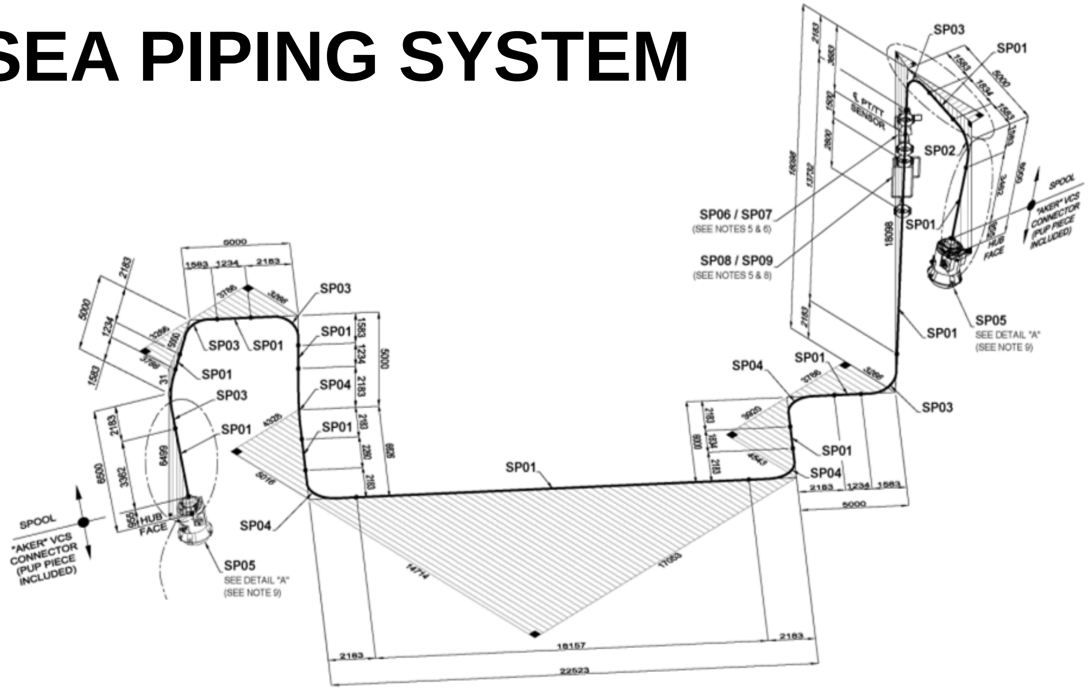
  - centrifugal forces exerted at direction change



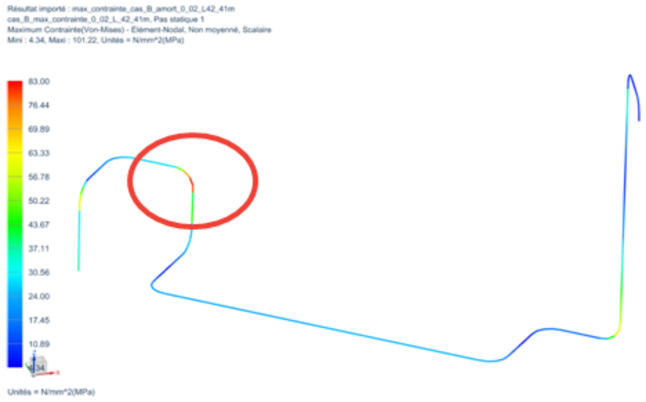



# APPLICATION ON A SUBSEA PIPING SYSTEM

- Typical 10” subsea pipe structure / approximately 80 m long
- First oscillation period 7s
- Pocket length can vary from 3 m to 91 m (longer that the pipe system) – velocity 3 to 7 m/s
- Maximum stress values always occur at the same locations
- Fatigue data extracted from DNV RP C20

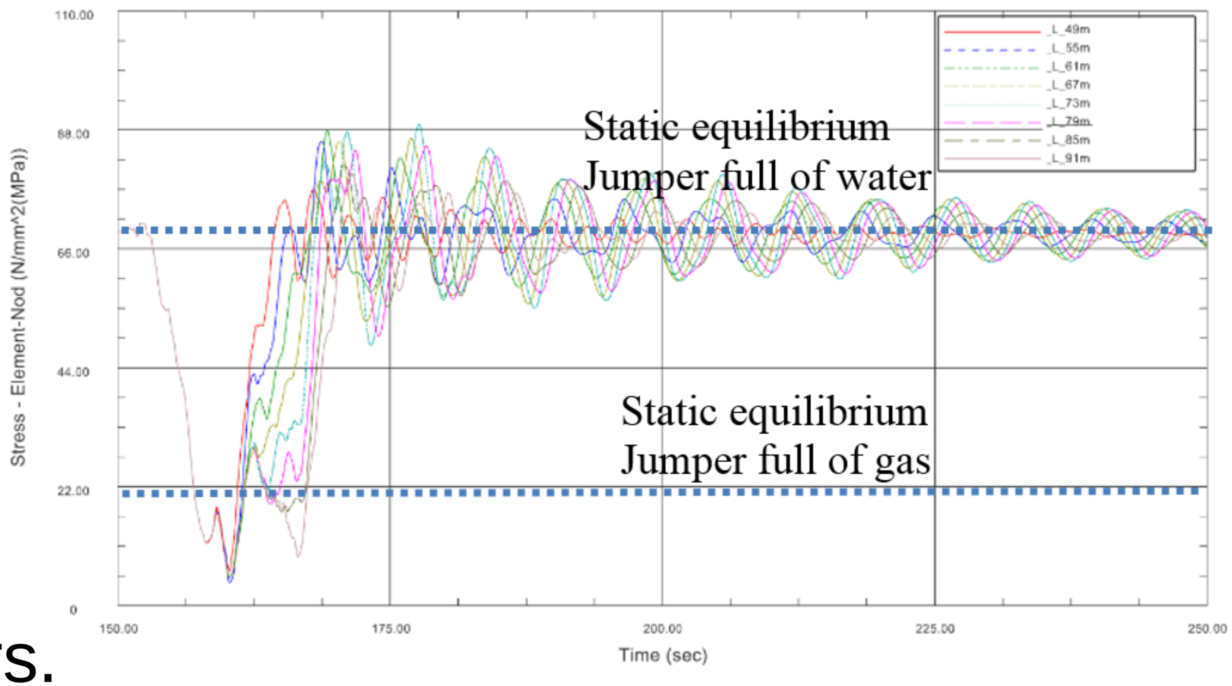



B - L = 42.41 m



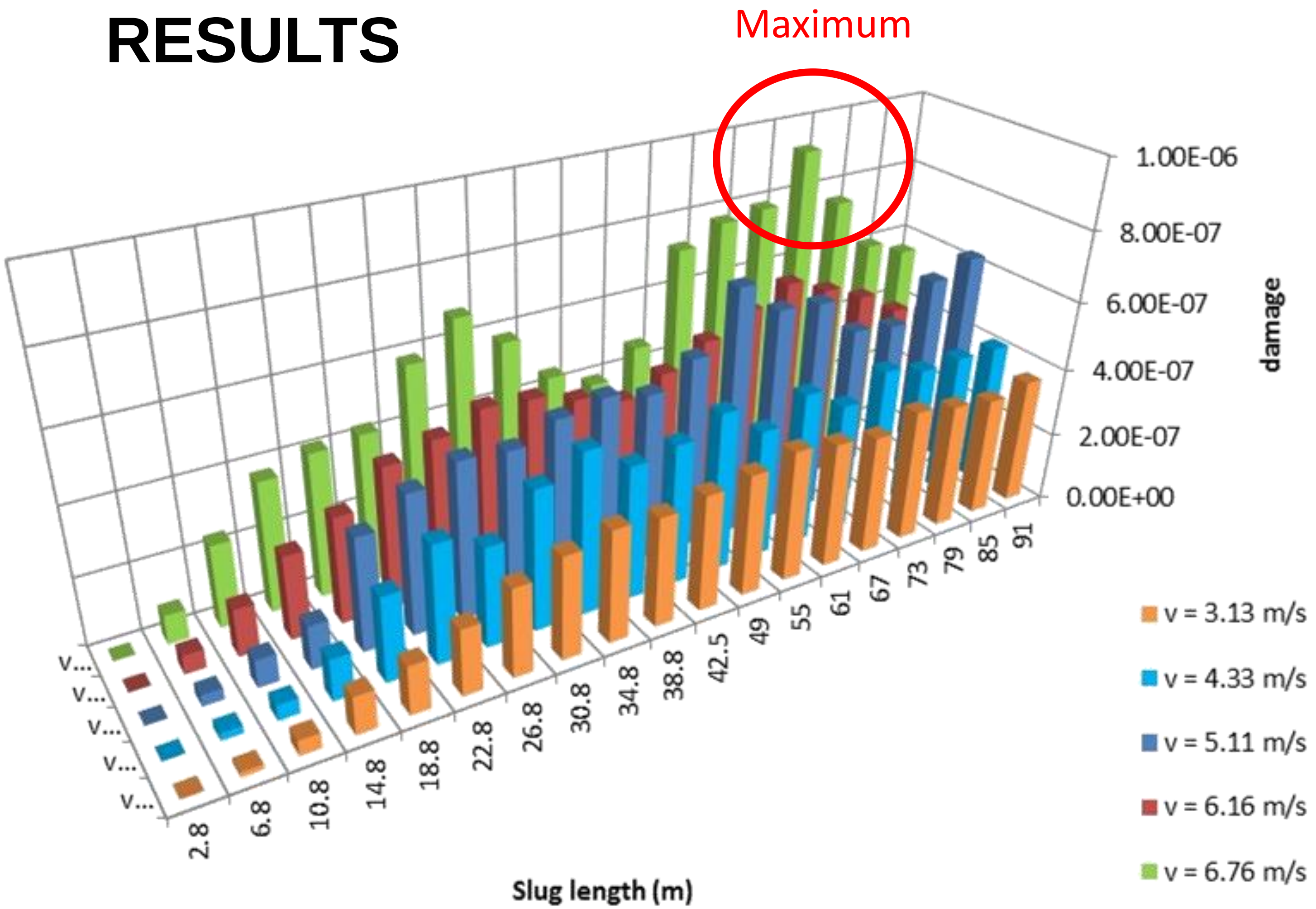
# RESULTS

- Longest slugs do not produce the worst-case conditions
- 73 m slug generates the highest displacement levels
- Difficult to estimate which configuration is the worst
- When the slug length is long enough, a static equilibrium occurs. This static position corresponds to the piping system full of gas.

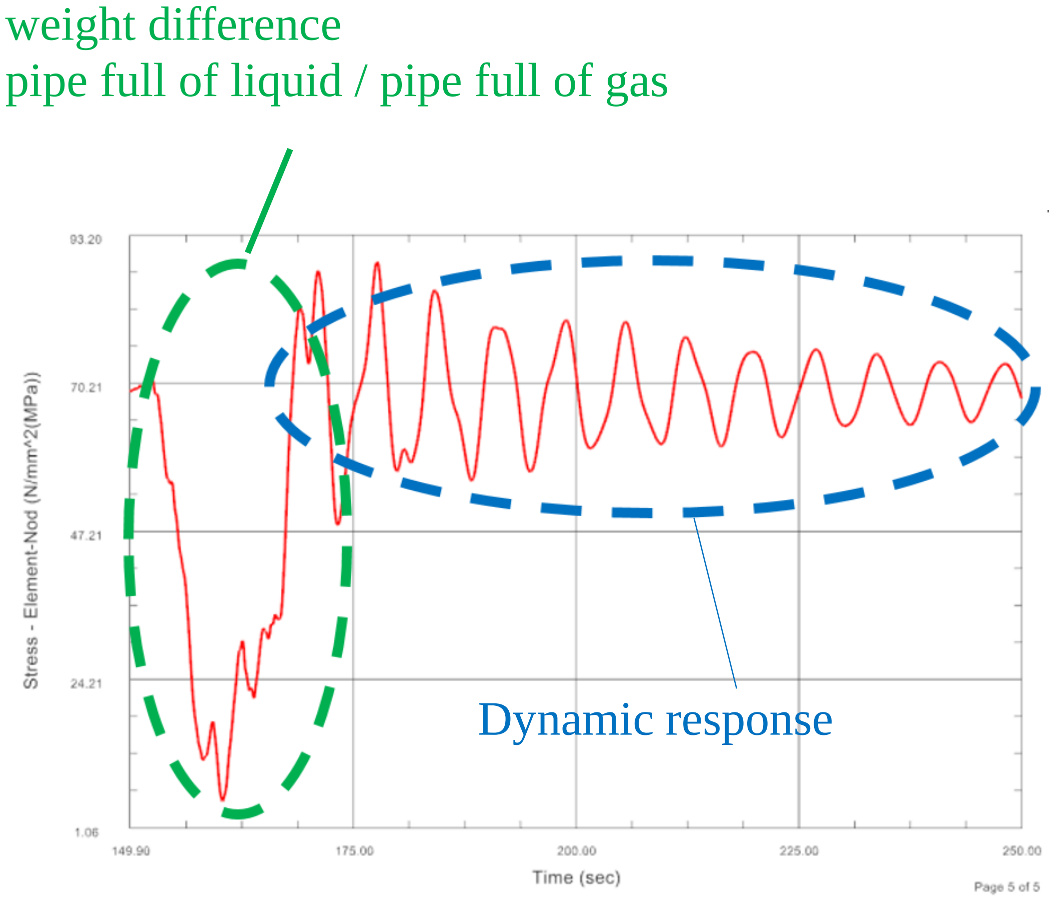


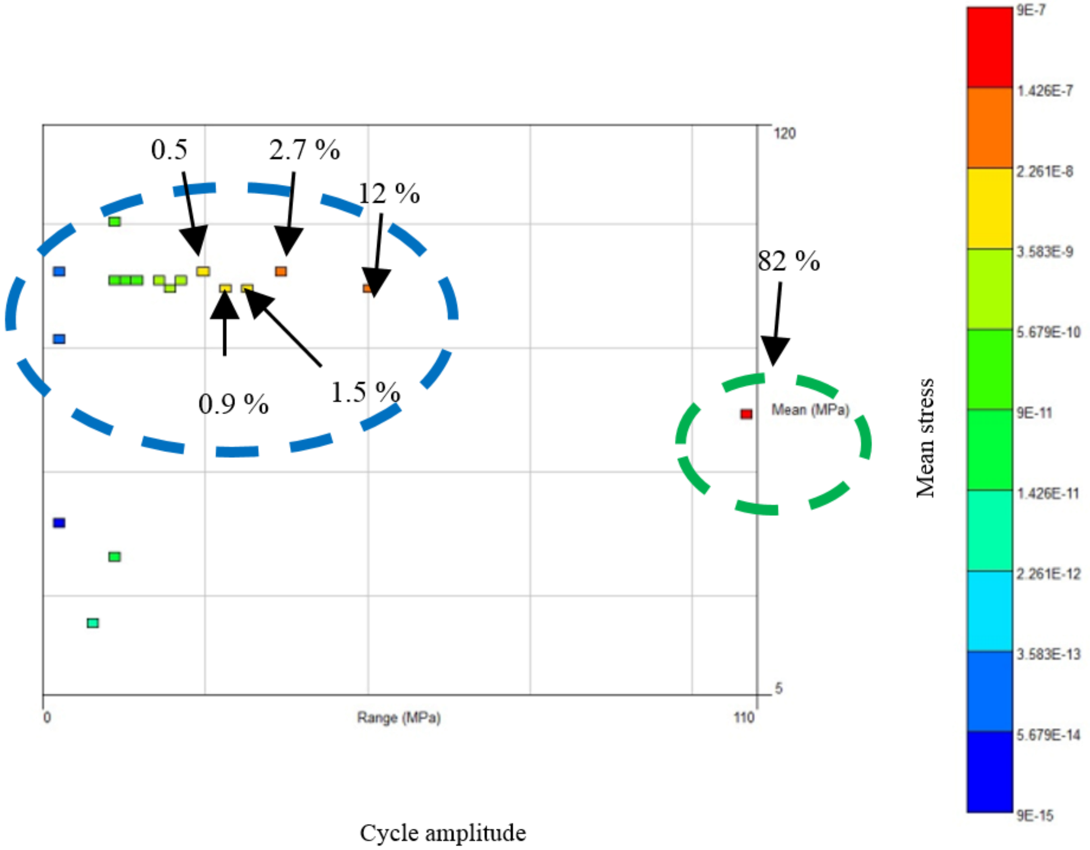
# RESULTS

- Damage computed for each of the different process conditions
- Coupling between bubble length, velocity and pipe geometry



# 73 M GAS POCKET DAMAGE RESULTS



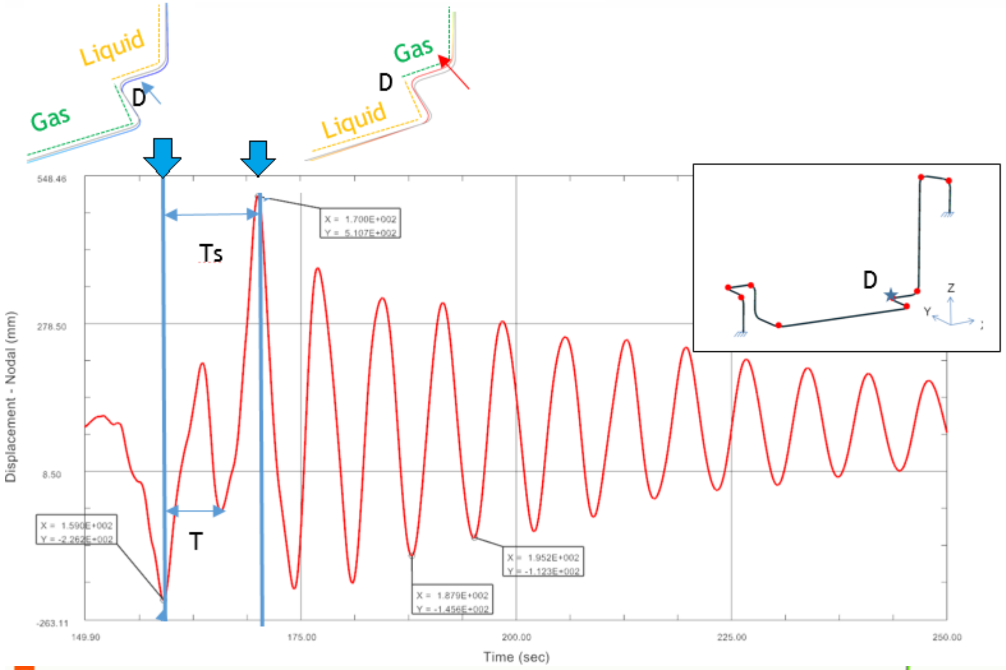



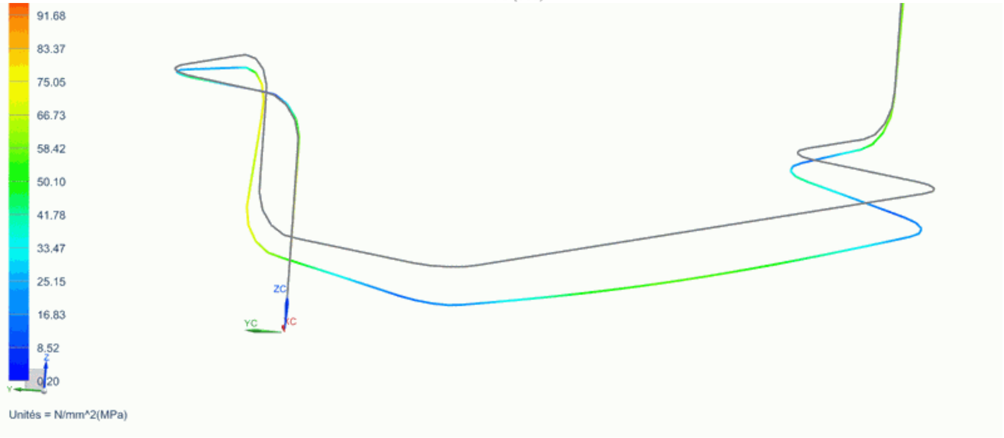
# 73 M GAS POCKET DAMAGE RESULTS

- Oscillation period (T) is 7.2 s, corresponding to the piping system first natural frequency

- Ts is 10.8 s = 1.5 times the oscillation period

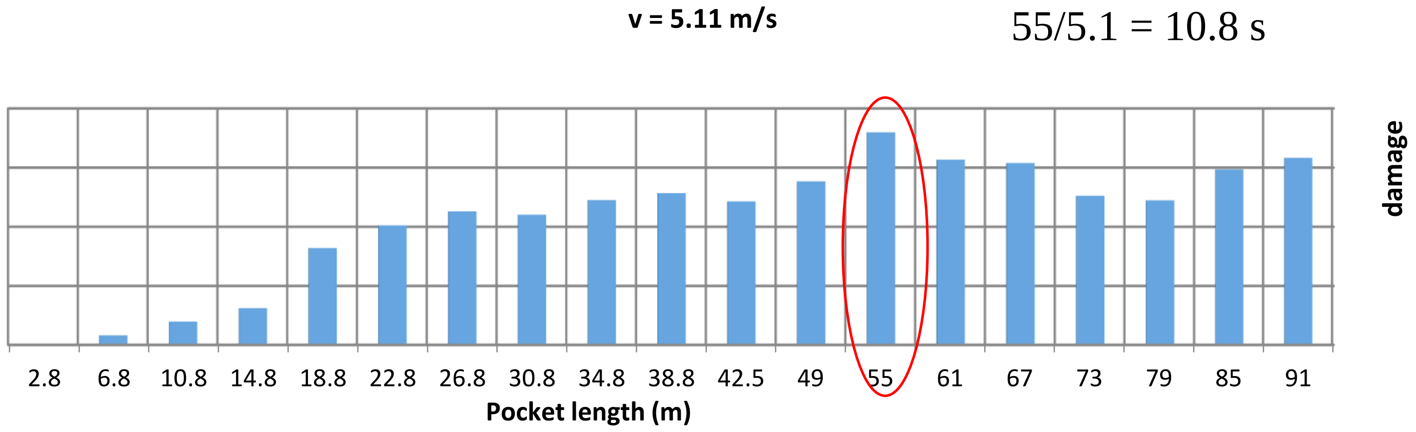
- Most unfavorable phase angle for this case

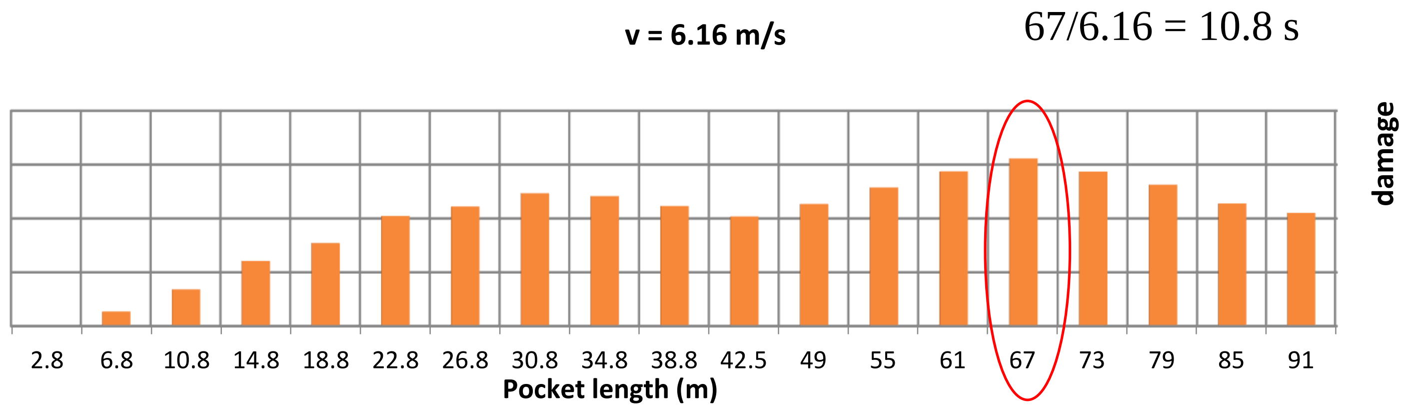


# VALIDATION ON OTHER CASES

- For other velocities, maximal damage was also computed for slug lengths with Ts approximately equal to 1.5 times the oscillating period (7.2 s).



# CONCLUSION

Maximum fatigue generated by slug regime depends on

- Pipe structure,
- Slug velocity,
- Slug length.

Highest vibration and stress levels are due to an unfavorable phase angle between the oscillating response of the structure and the dynamic excitation applied to it.

Quasi-static approach and average slug parameter method now recognized as non-conservative.

# Thank You / Questions

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