ICorr and TWI Welcomes

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DISSERTATION SUMMARY PRESENTATION

AN INVESTIGATION INTO THE WRINKLING PHENOMENON ON CRA LINED PIPELINES AND ITS IMPACT ON PIPELINE INTEGRITY

AGENDA

- Use of CRA’s
- Pigging Definitions
- Introduction
- Literature Review
- Background on PL1and PL2 & Project Objectives
- Analyses
    - Circumferential Deformations Near The Girth Welds
    - Waved Pipe Wall Surface Comparison Of Wrinkling To IP Results
    - Comparison of Caliper Pig Tool runs with IP results
    - Impact of Cleaning Pig Tool
    - Corrosion Mechanisms and Corrosion rates
- Conclusions
- Recommendations

USE OF CRA'S

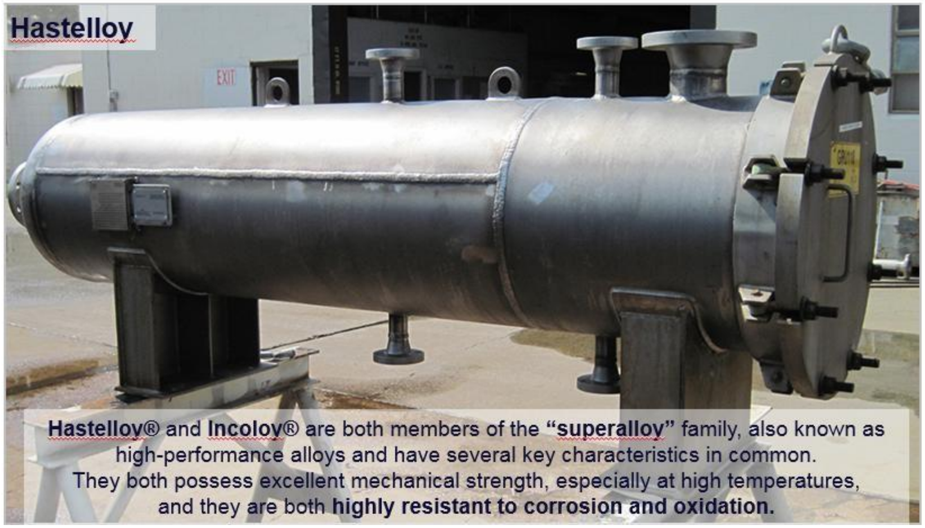
CRA - CORROSION RESISTANT ALLOY

APPLICATIONS

Super Duplex Stainless Steel - Often Used for High Flow / High Erosion Risk Conditions

CRA - CORROSION RESISTANT ALLOY

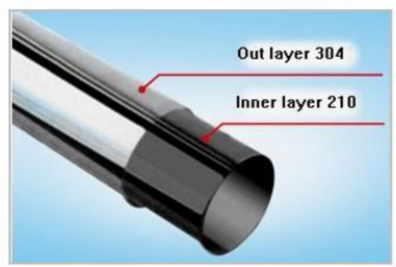
FULL CRAVESSEL



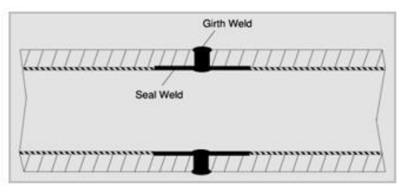
Very High Cost

APPLICATIONS

CRA LINED PIPES



Much Lower Cost



Jointing

Claddings are OK For Short Lengths

PIGGING DEFINITIONS

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To monitor integrity, **three types of pigs used:**

- **Cleaning pig**

- **Semi-intelligent pigging**

- **Intelligent Pigging (IP)**

INTRODUCTION TO PROJECT

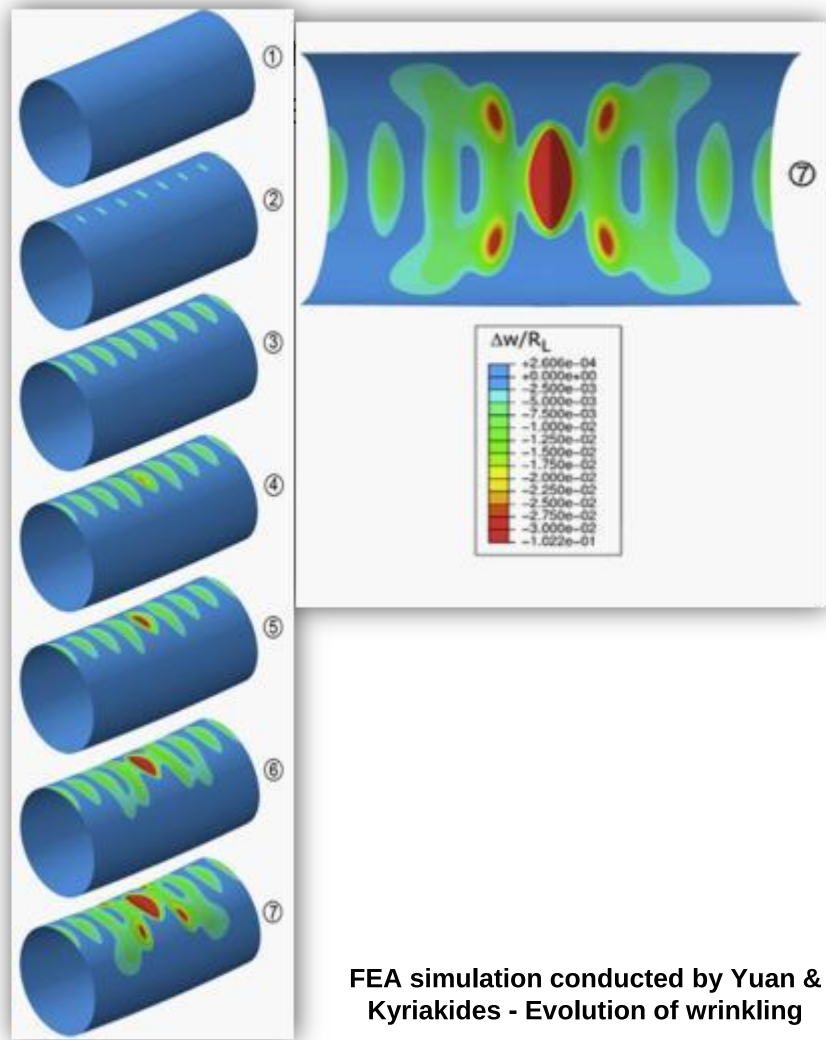
INTRODUCTION

- **Mechanically bonded lined CRA pipelines are becoming more commonly used in the Oil & Gas Industry**
  - Mitigates against corrosion
  - No requirement for corrosion inhibition
  - Cost effective when compared to Solid CRA or Clad
- **However there are some negatives in installation and operation:**
  - Bending
  - Buckling
  - Tension
  - Internal/External Pressure
- **One of the known anomalies arising is the phenomenon of wrinkling of the CRA liner**

LITERATURE REVIEW

LITERATURE REVIEW

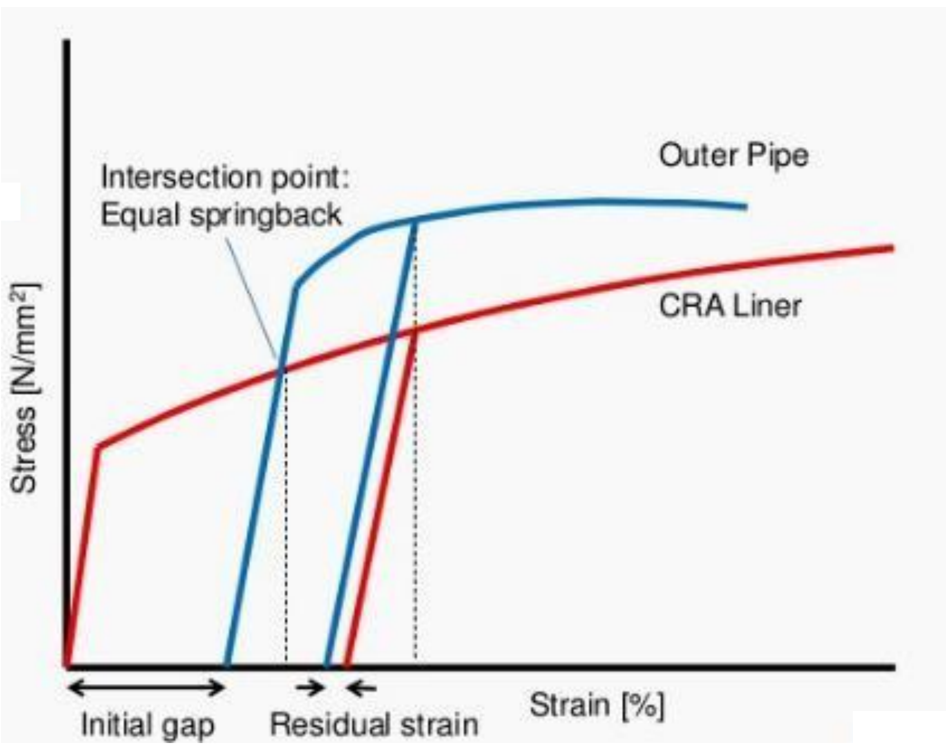
- Yuan and Kyriakides carried out FEA on the lifespan of a wrinkle leading to failure
  - **Image 1** – Ovalised pipe
  - **Images 2 & 3** – Periodic disturbances of small to medium amplitude wrinkles – also known as first stage of bifurcation
  - **Images 4 & 5** – Wrinkling localises at mid-span and a diamond buckling mode becomes apparent.
  - **Image 6** – Onset of second stage of bifurcation
  - **Image 7** – Butterfly shaped deformation with a major

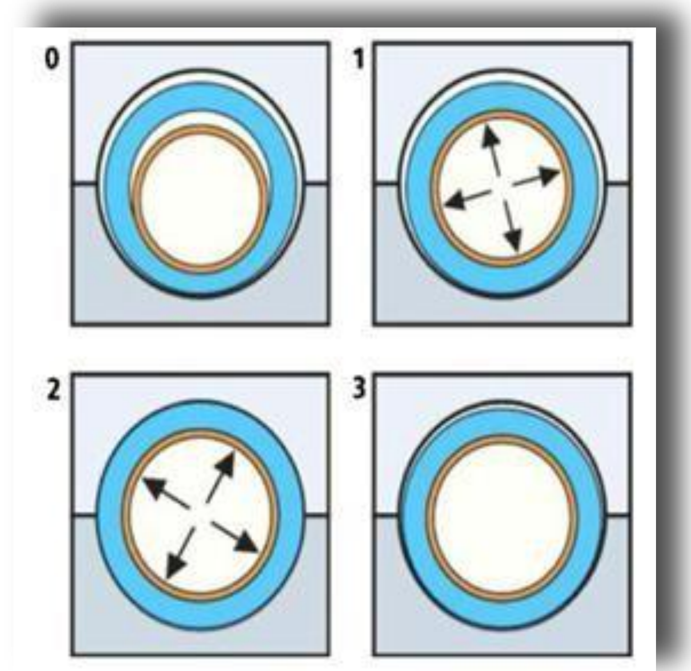


FEA simulation conducted by Yuan & Kyriakides - Evolution of wrinkling

LITERATURE REVIEW (CONT)

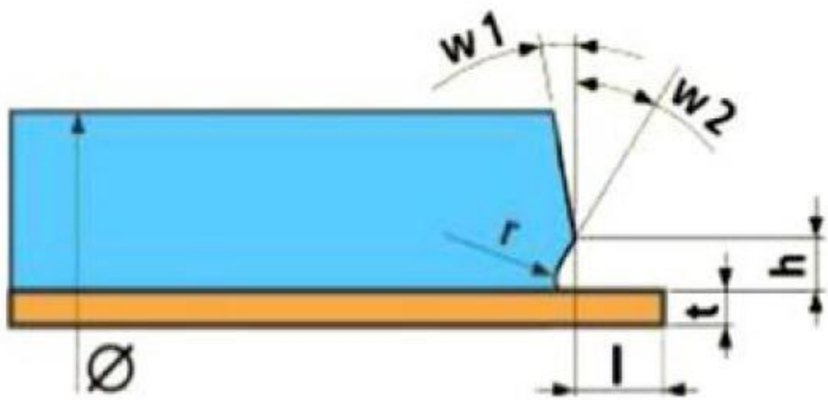
- **Potential Causes of Wrinkling in all stages of pipeline life cycle from manufacture to operation.**
  - Annular Gap
  - Thermal Stresses

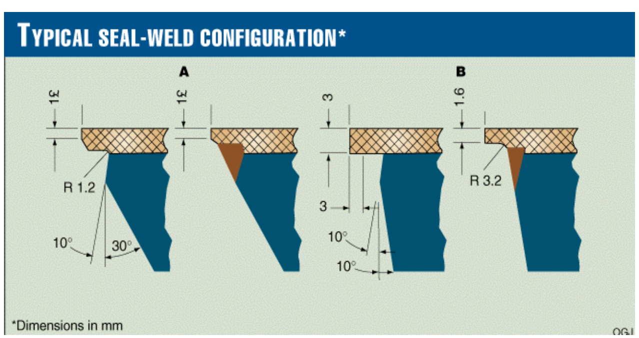


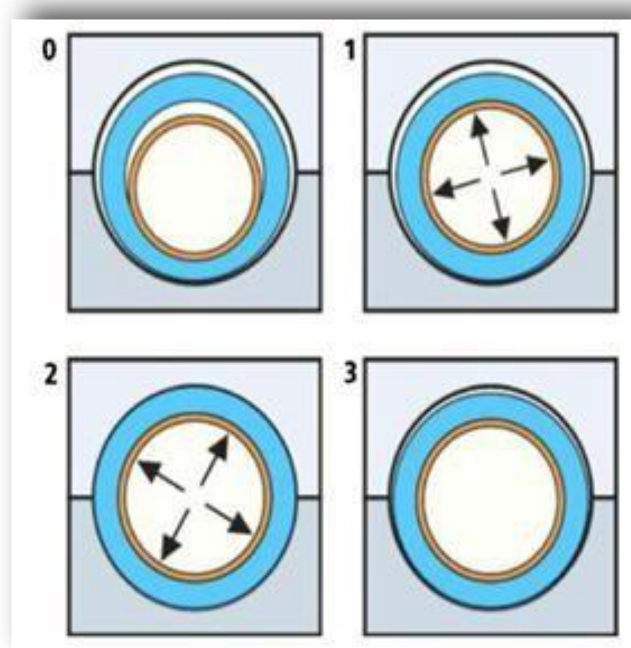


Bu-Bi Lined Pipe Manufacturing Process

- **Potential Causes of Wrinkling in all stages of pipeline life cycle from manufacture to operation**
  - Annular Gap
  - Thermal Stresses



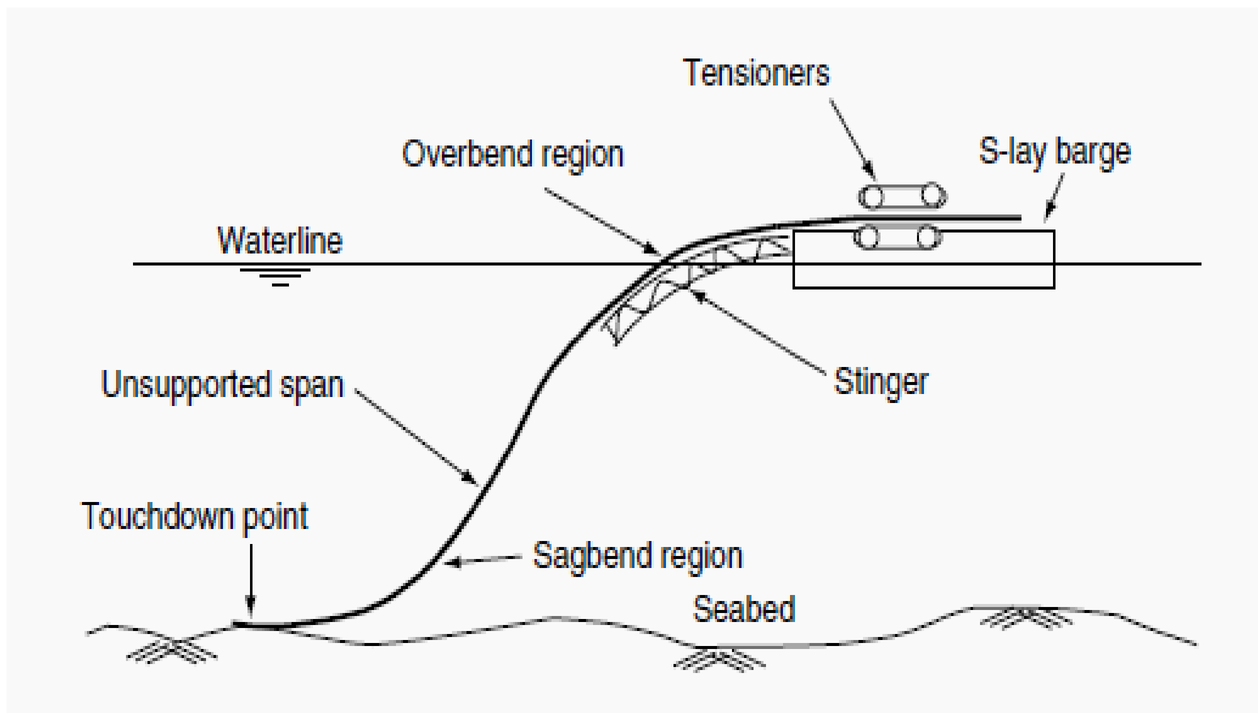




Bu-Bi Lined Pipe Manufacturing Process

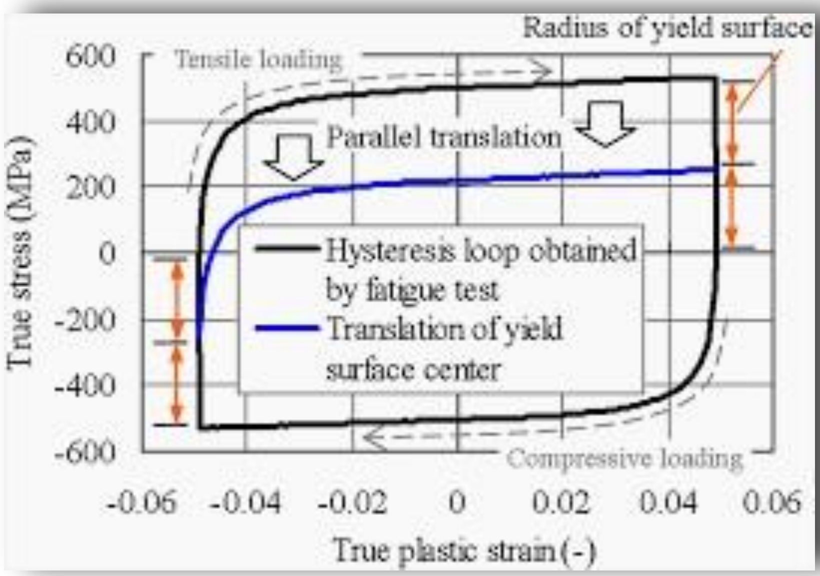
LITERATURE REVIEW (CONT)

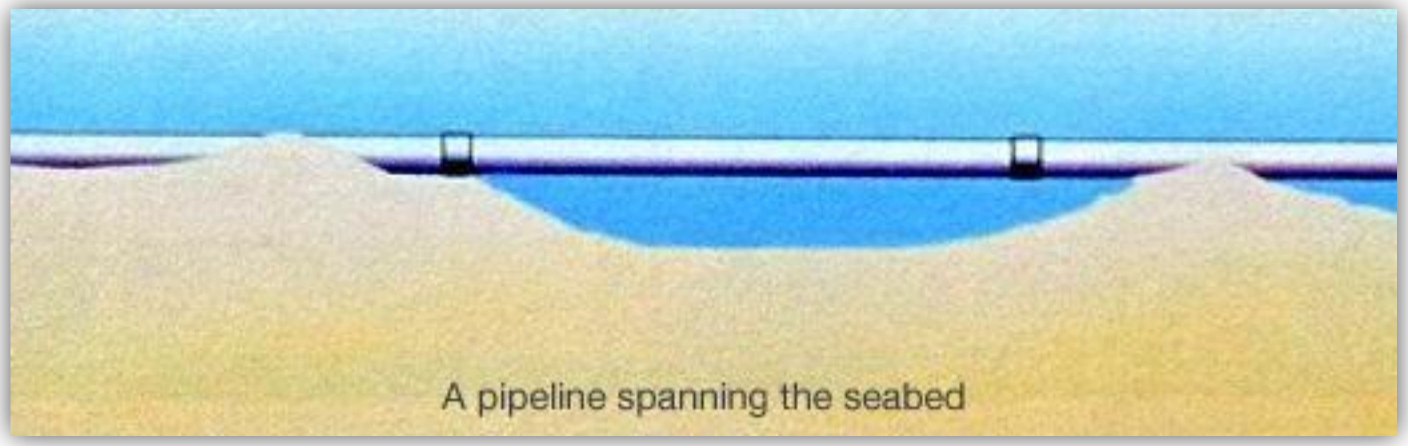
- **Potential Causes of Wrinkling in all stages of pipeline life cycle from manufacture to operation**
  - Bending Stresses
  - Internal pressure



LITERATURE REVIEW (CONT)

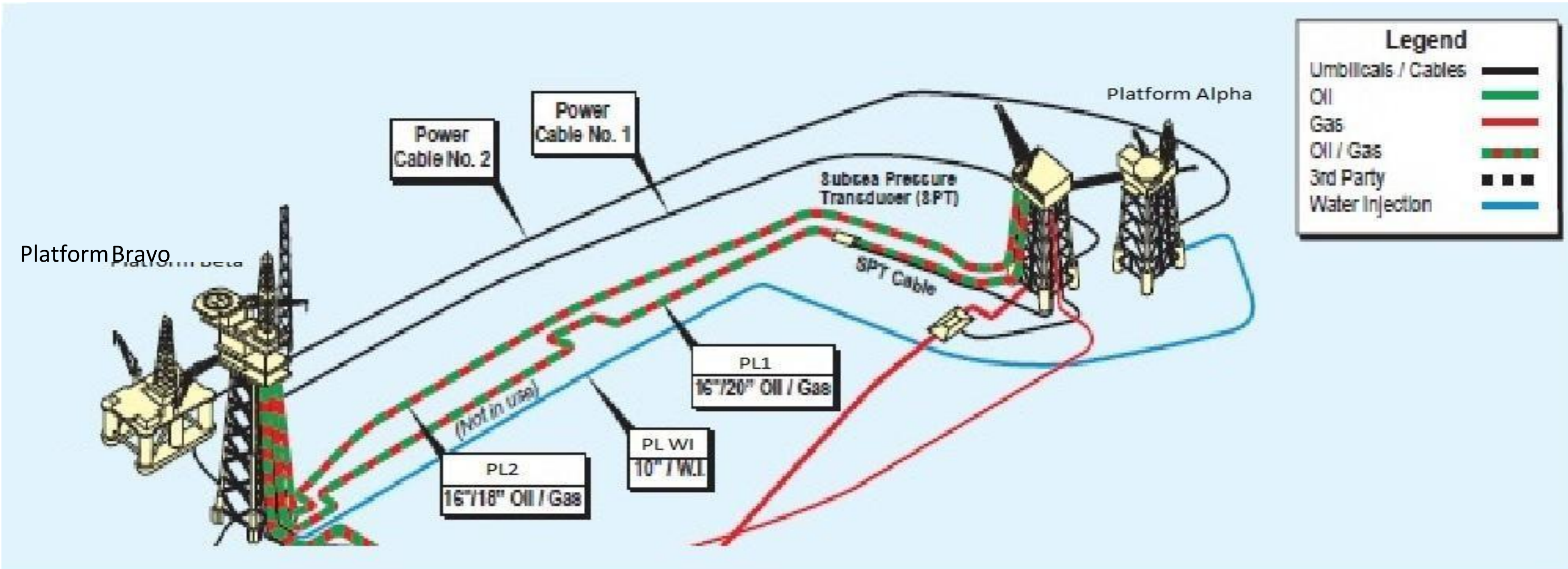
- **Potential causes of Wrinkling growth**
  - Axial Cyclic Loading
    - Pressure & temperature cycling
  - Free spanning



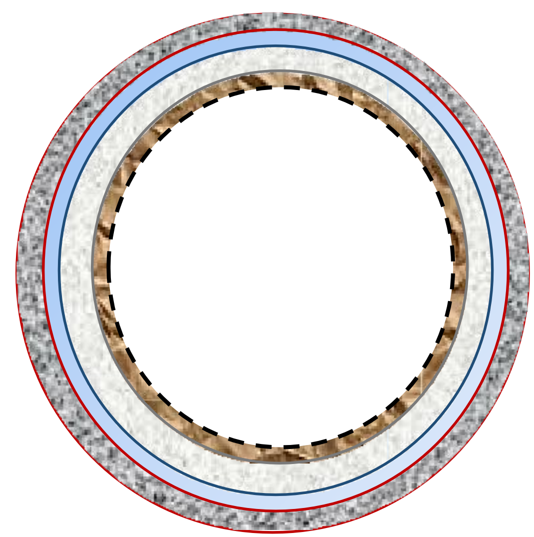


BACKGROUND ON PL1 AND PL2

BACKGROUND ON PL1 & PL2



- PL2 is a 16”/18” Pipe-in-Pipe pipeline transporting hydrocarbons from Bravo to Alpha
- **PL2 was a replacement for PL1 in 2008 due to:**
  - **Under scale corrosion**
  - **Low remaining wall thickness**
- Lessons learned implemented
  - 3mm CRA liner
  - Rigorous scale removal tools
  - Monitoring of scale build up with pigging tool runs
- **Baseline intelligent pig in 2008 of PL2** identified potential wrinkling of the liner, noted in subsequent caliper pig runs



PROJECT OBJECTIVES

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- Determine whether the geometrical anomalies are associated with the CRA liner, and if so, causes of such anomalies.

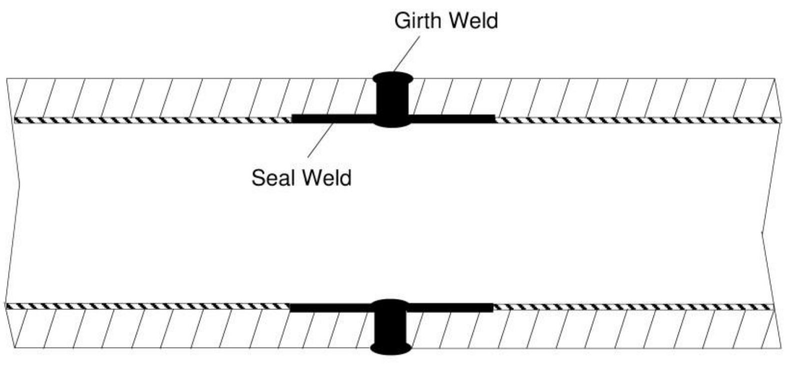
- Compare and review the baseline inspection results for PL2 with the data from the five runs carried out by a calliper pig with debris measurement capability between the years 2009-2015.

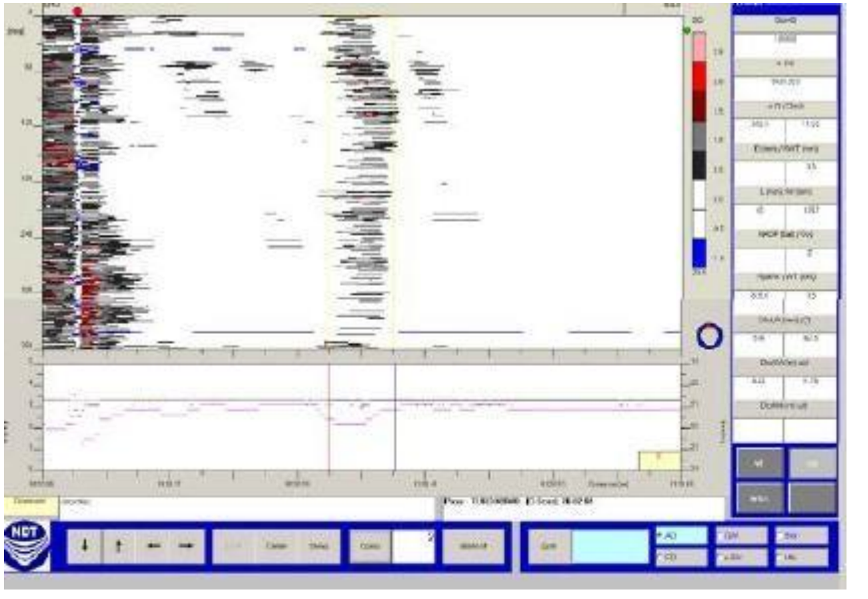
- Identify risks associated with continued operation; including calculated time to failure should there be a localised defect.

ANALYSES

ANALYSES OF THE CIRCUMFERENTIAL DEFORMATIONS, NEAR THE GIRTH WELDS

- BUTTING BuBi® pipes with the CRA liners are terminated with a seal weld and a 50mm overlay weld.





- Reference from OMAE2014-23577 – Wrinkling and Collapse of Girth-welded Lined pipe under bending.

- **Under bending, this configuration prevents the separation of the liner from the steel pipe thereby creating a periodic disturbance in the liner. This disturbance is sufficient to cause wrinkling.**

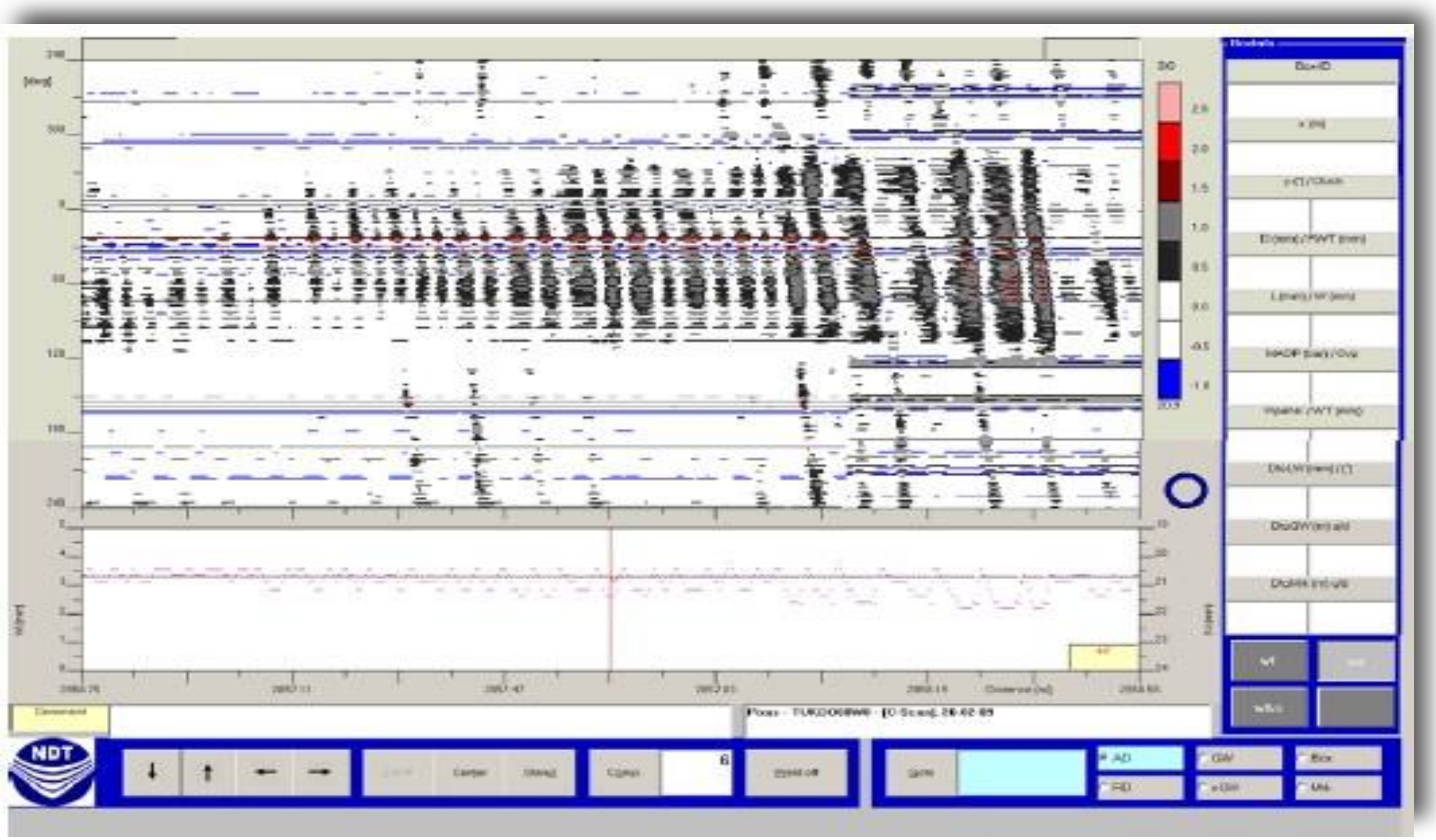
ANALYSES OF WAVED PIPE WALL SURFACE

- **Excerpt from one of the research papers show that the waved pipe areas of the CRA liner could be the initial stage of bifurcation.**

  - Mechanical Behaviour and wrinkling of lined pipes by *Vasilikis, Karamano states that,*

    "Prior to bifurcation, the pipe exhibits uniform deformation along its length in the form of cross-sectional Ovalization. At buckling, a wavy pattern shape suddenly occurs in the form of uniform wrinkling at the compression side of the liner pipe"

ANALYSES OF WAVED PIPE WALL SURFACE



Sample of Baseline inspection from the intelligent pig run carried out post installation

ANALYSES OF WAVED PIPE WALL SURFACE

Fig. 1. Lined pipe, (a) photo after experimental testing (Focke, 2007) and (b) wrinkled liner pipe (Hilberink, 2011).

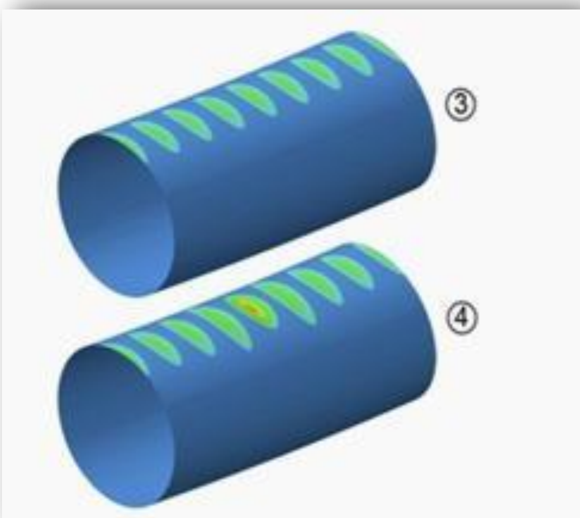
- Experimental observations (Focke, 2007) have indicated that the long lined pipe, after the occurrence of uniform wrinkling of the liner pipe (“wrinkling area 1 in Fig. 1b),
- Exhibits a second bifurcation in the form shown in “wrinkling area 2” of Fig. 1b. More specifically, one of the wrinkles grows rapidly,
- Forming one main buckle, symmetric about the plane of bending (denoted as (A) in Fig. 1b), and four minor buckles (denoted as (B) in Fig. 1b) from either side of the main buckle. The wavelength of the secondary buckling pattern is equal to twice the wavelength Lhw of the first buckling pattern.

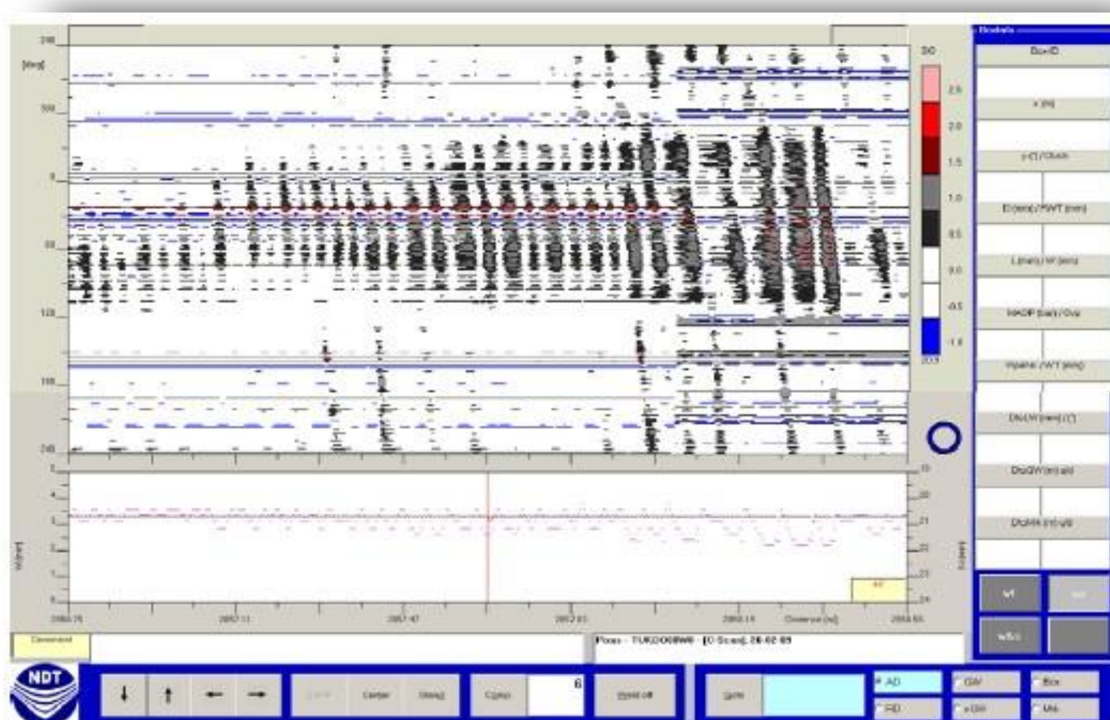
ANALYSIS – IMPACT OF PIGGING TOOL

- Aggressive scale removal tools remove the wrinkles **exposing** areas of carbon steel to corrosive fluids.

ANALYSIS – COMPARISON OF WRINKLING TO IP RESULTS

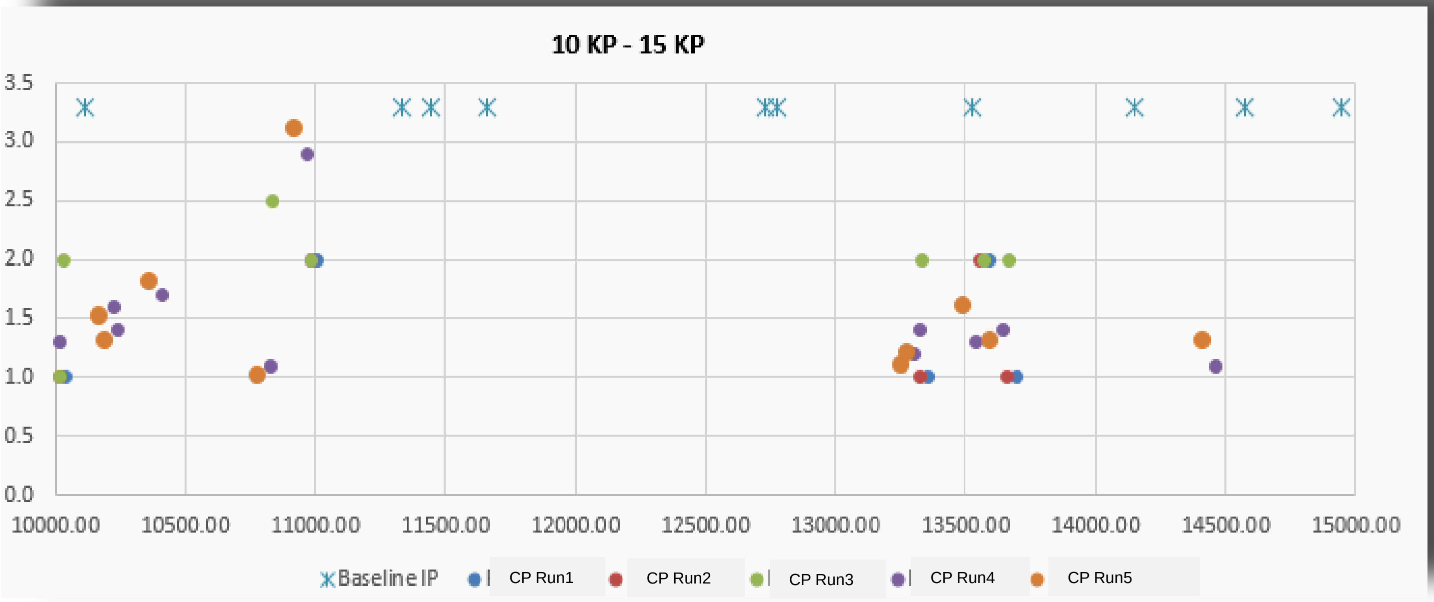
- **Baseline intelligent pig run in 2008 identified potential wrinkles**
- Wrinkles <u>appear to</u> match up with Stage 3 & 4 deformations determined by Yuan & Kyriakides
  - Not yet Stage 6 and 2nd bifurcation





ANALYSIS – COMPARISON OF CALIPER PIGGING TOOL RUNS WITH IP RESULTS

- Main objectives of this study is the comparison between the IP results and the 5 caliper pigging tool (CPT) runs over the 9 years of PL2 operation
- **An example shown below**, shows that the IP and caliper pigging tools are different and they record different sets of data.
- Although some areas have been noted to coincide showing wrinkles formed post installation have not progressed to secondary bifurcation



ANALYSIS – CORROSION MECHANISMS & CORROSION RATE FOR PL2

- Calculations taking into consideration two approaches
  - Optimistic approach with 95% corrosion inhibition and 5 % no inhibition;
  - Pessimistic approach with no corrosion inhibition and no CRA liner.

- **Modelling Outcomes**
  - Optimistic Approach –
    - Remaining Safe operating life > field life
  - Pessimistic Approach
    - Remaining safe operating life of 4 years
    - Similar to the scenario in PL1, hence routine cleaning programme should be maintained.

ANALYSES OF WAVED PIPE WALL SURFACE

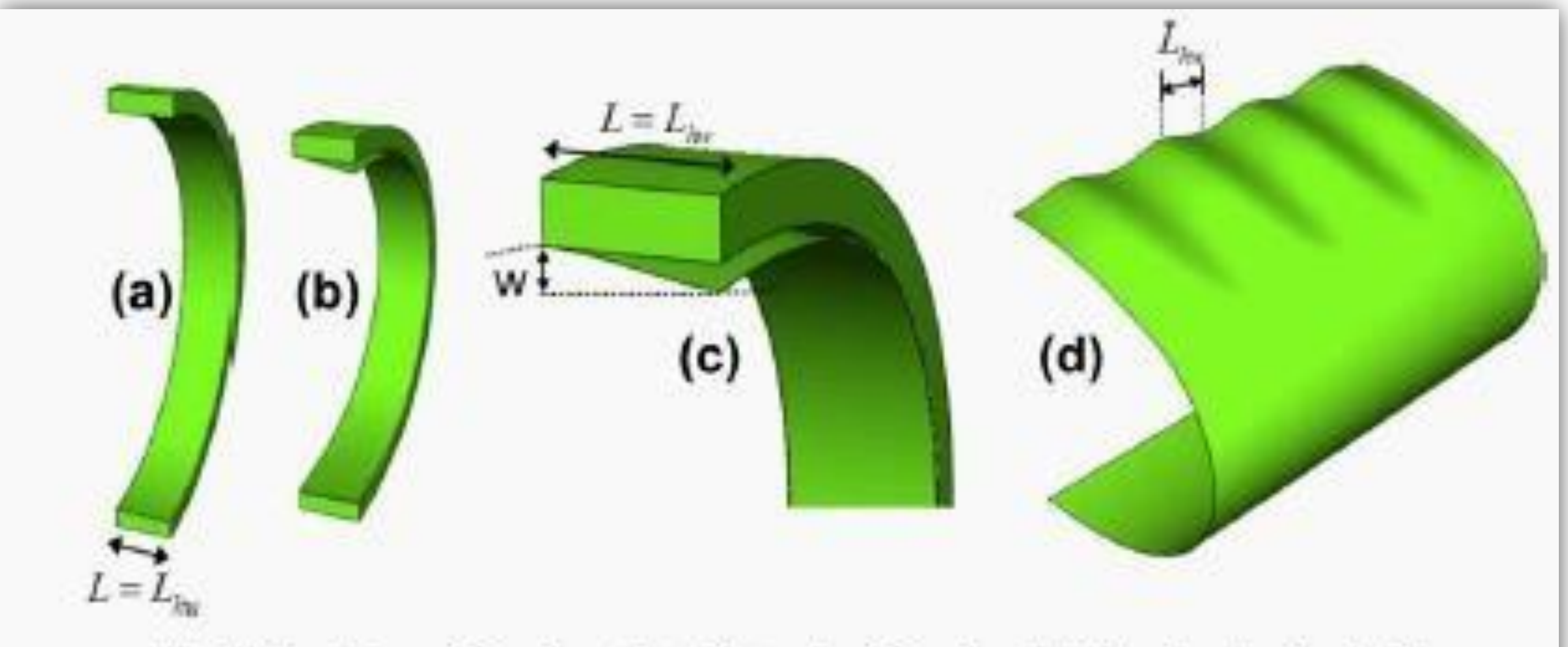


Fig. 12. lined pipe configurations; (a) undeformed configuration; (b)-(d) ovalized and buckled liner.

- The above figure gives an idea on the transition **from the ovalization to wrinkle formation.**
- Numerical analyses for calculating the wrinkle growth has compared well with the test measurements carried out (Mechanical behaviour of wrinkling of pipes).

ANALYSES OF WAVED PIPE WALL SURFACE

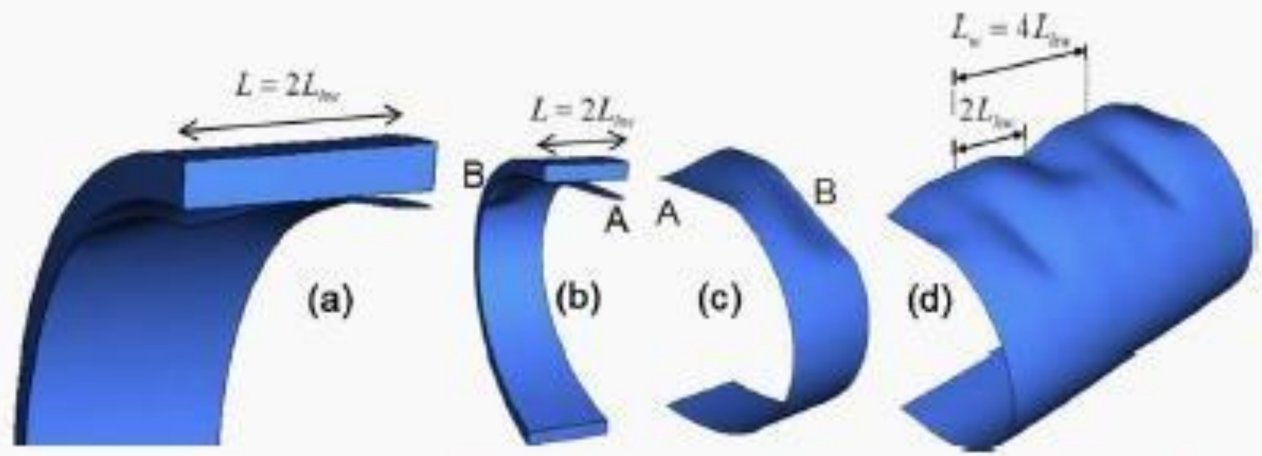


Fig. 14. (a) Initial configuration with liner wavy imperfection and (b)-(d) deformed (buckled) configuration of lined pipe after secondary bifurcation.

- Through experimental observations, it was noted that when the applied curvature reaches a certain value, the liner deformation bifurcates to the shape shown
- In Fig. (b) and (c) above. Simulating the secondary buckling may not be possible as it is still under study.

CONCLUSIONS

CONCLUSIONS

- CRA lined pipelines used as a cost effective means of mitigating internal corrosion.
- Some negatives noted for CRA lined PIP systems from design through to installation.
  - Example of concern is wrinkling phenomenon in mechanically bonded liners.
  - Yuan and Kyriakides illustrate the life span of a wrinkle leading to a failure scenario.
- PL2 was replacement of PL1 which had suffered under-scale corrosion.
  - CRA liner used to mitigate this corrosion.
  - IP identified deformations to PL2 liner.

CONCLUSIONS

- First task
  - determine whether deformations are wrinkles
- Second task
  - assess whether wrinkles have grown and are close to liner failure.

- Worst case scenario assumed –
  - Abrasive cleaning tools have eroded the liner exposing small areas of carbon steel.
  - Corrosion defect assessment undertaken
    - Maintaining corrosion inhibition gives remaining safe operating life > field life
    - **Without inhibition and removal of the liner reduces the safe operating life to 4 years**

RECOMMENDATIONS

RECOMMENDATIONS

- Repeat the IP run on PL2 to get a reproducible data set.
- Conduct a Finite Element Analysis to confirm inferred condition of the pipeline
- Optimise pigging frequency to reduce the risk of damage to wrinkles
- Include liner configuration in Finite Element Analysis in future designs
- Internally pressurize the pipeline during installation to avoid issues of dis-bonding of the liner
- New product development – glued mechanically lined pipe

YOUR QUESTIONS PLEASE