Dynamic Stress due to End Effects in Non-bonded Flexible Pipes

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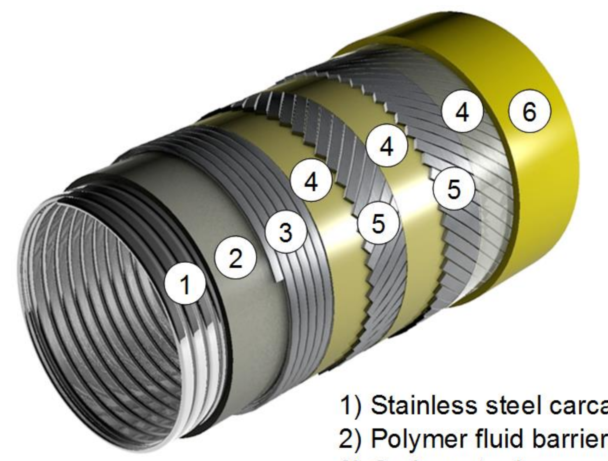
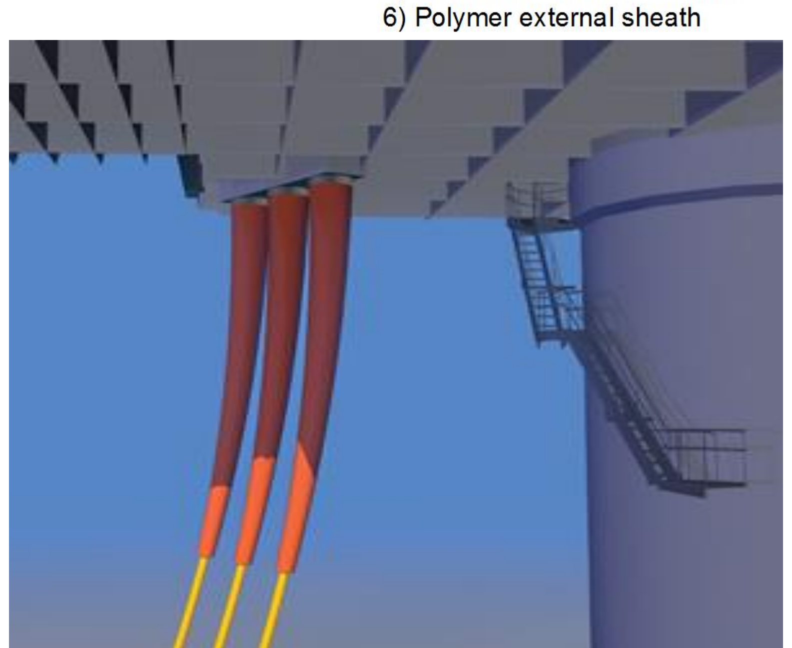
Introduction

The flexible riser represent a vital part of many oil and gas production systems. Failure in the riser section may cause loss of lives, environmental pollution and threaten the field economy. One of the most critical failure modes is corrosion fatigue in the tensile armour steel layers due to the combined action of dynamic loads and corrosion from the annulus and seawater environments.



1) Stainless steel carcass
2) Polymer fluid barrier
3) Carbon steel pressure armour
4) Anti wear / birdcaging tapes
5) Carbon steel tensile armour
6) Polymer external sheath

A flexible pipe is terminated with an end fitting where all layers are anchored and clamped in a special end structure. To limit the bending stresses and excessive curvature a bend stiffener is added to improve the stiffness of the flexible pipe which connecting the end fitting.There are two kinds of flexible pipes which named as bonded and non-bonded pipe. For non-bonded pipes, the cylindrical layer is able to slide relative to adjacent layers.



objective and scope

- Establish necessary input for flexible riser local stress and fatigue analysis for two cross-sections.
- Establish local Bflex models for the flexible pipe cross-section using ITCODE 0 and ITCODE31 for two cross-sections and for start BS at 0, 0.25 , 0.5 and 0.75 pitch from end fitting.
- Perform fatigue stress analysis in Bflex using the above models and compare the results in terms of stress history plots and fatigue contribution from each load case at different longitudinal load for a typical SN curve.

Methods and Assumptions

Non-linear finite element method

Local stress analysis

Plane surfaces remain plane until slip

Geodesic and Loxodromic assumptions

Modeling

Two types of models with different cross sections are used for analysis in this thesis: ITCODE 0 and ITCODE 31. Original model refers to the model with 0 pith gap between the end fitting and bend stiffener; modified model refers to the model with 0.25, 0.5, 0.75pitch length gap.

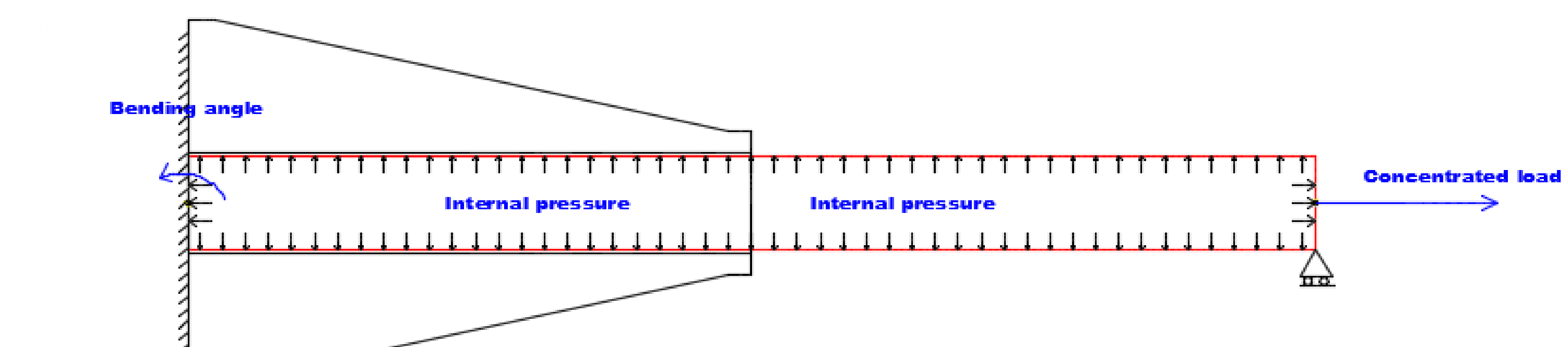
Model (Inner Tension Layer and Bending Stiffener)

The gap lengths for the modified models are calculated according to the pitch length of the inner layer (tenslayer1). All the important parameters are shown in table below:

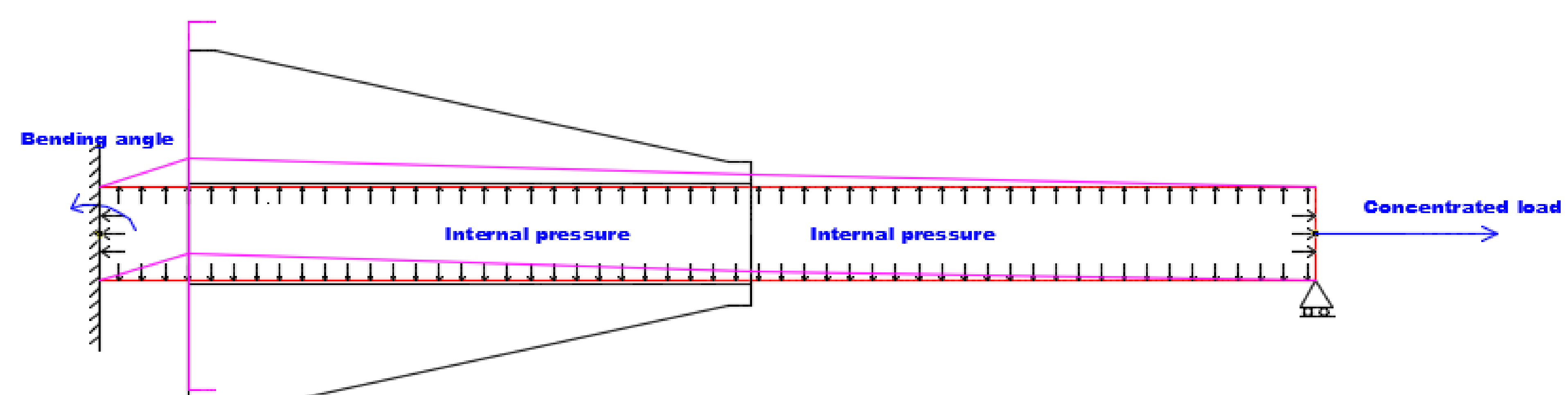
	Original (0 pitch gap)		0.25 pitch gap		0.5 pitch gap		0.75 pitch gap	
$L_0\,[mm]$	10000		10252.95		10505.89		10758.84	
Tenslayer	1	2	1	2	1	2	1	2
$R[mm]$	135.1	141.2	135.1	141.2	135.1	141.2	135.1	141.2
α [rad]	-0.69806	0.69808	-0.69806	0.69808	-0.69806	0.69808	-0.69806	0.69808
$L_p\,[mm]$	-1011.79	1057.419	-1011.79	1057.419	-1011.79	1057.419	-1011.79	1057.419
$\theta_1[\,^\circ]$	-62.1	59.42	-63.671	60.923	-65.242	62.426	-66.812	63.929
$\theta_0[\,^\circ]$	0	0	-1.5708	1.503	-3.1416	3.006	-4.7124	4.509

Model simplification

The model with the boundary condition and the load history can be simplified as the figure below:



Original model

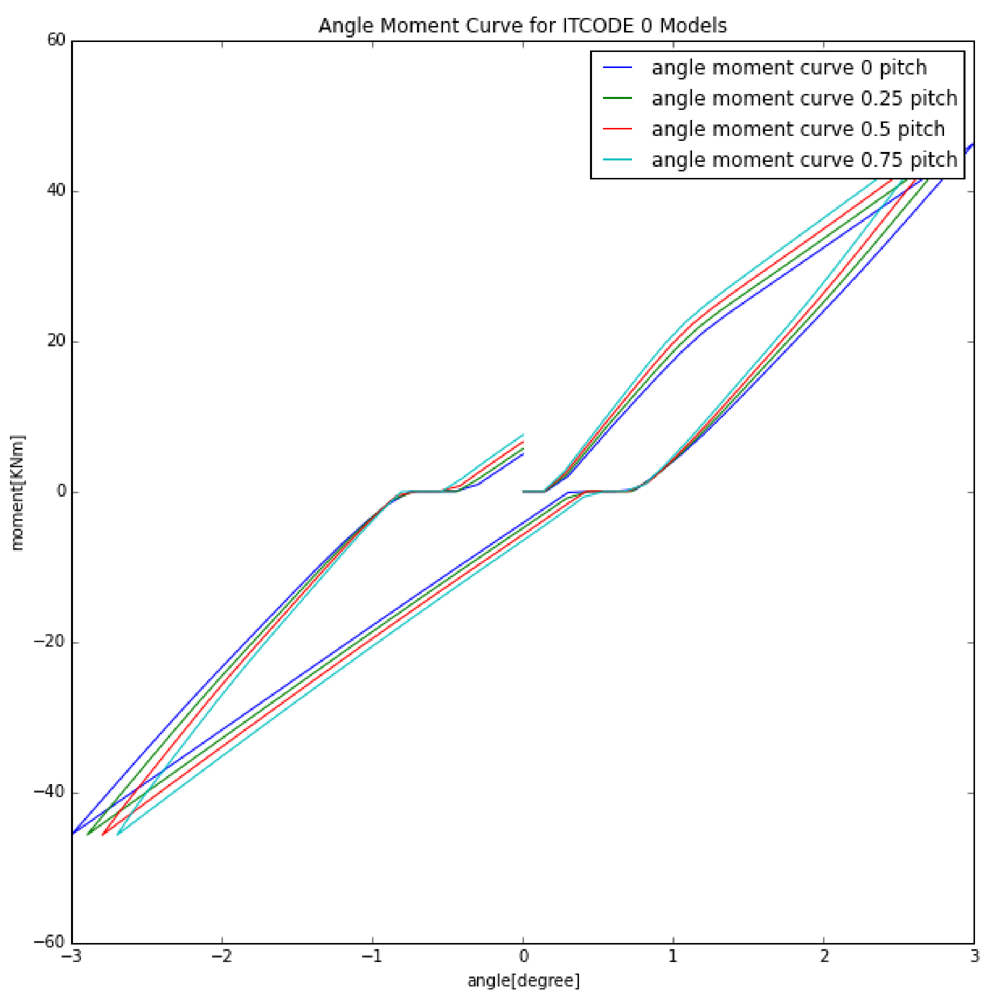


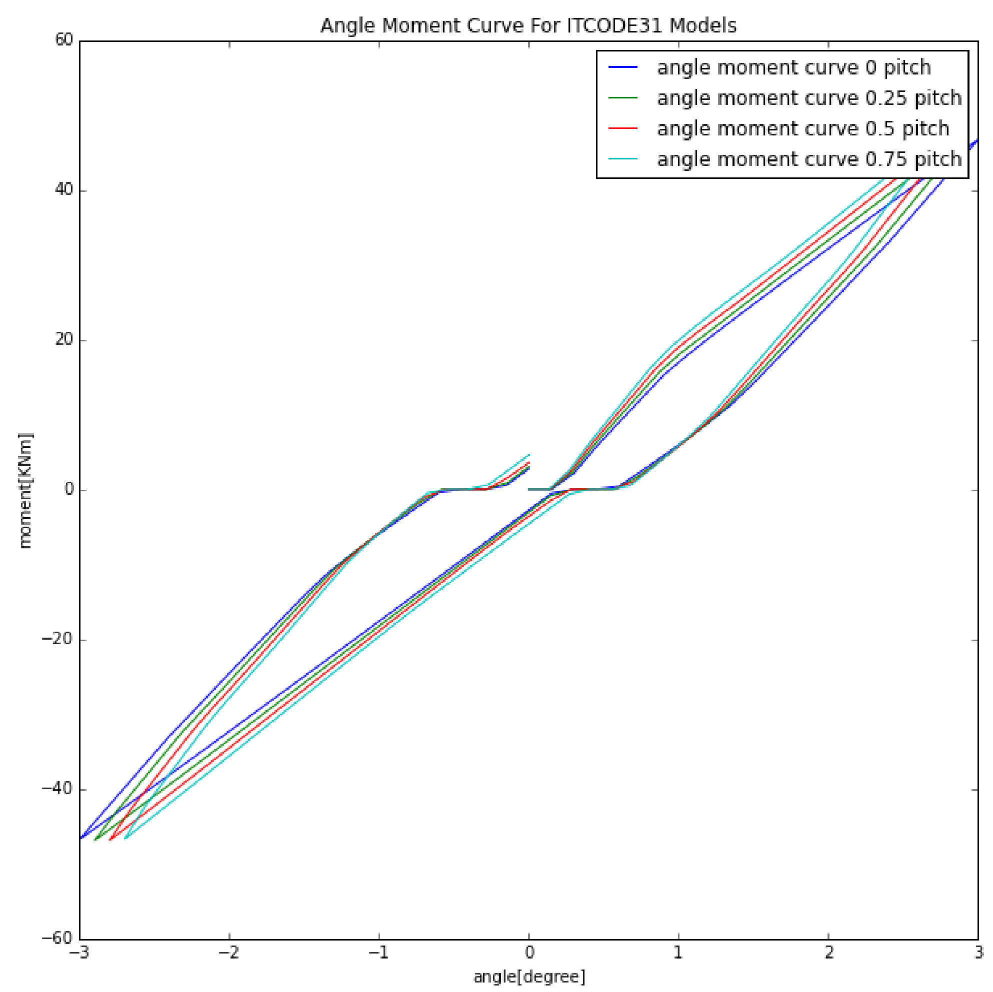
Modified model

Results and Discussion
Comparison and summary of moment and angle curve of both model itcode0 and itcode31

Keep node 501 (the end node of the bending stiffener) has the same largest moment during the load history. The results of the relative bending angle are show in the table and figure below:

Gap length	0 pitch length		0.25 pitch length		0.5 pitch length		0.75 pitch length	
Units	Angle [degree]	Moment [KNm]	Angle [degree]	Moment [KNm]	Angle [degree]	Moment [KNm]	Angle [degree]	Moment [KNm]
ITCODE0	3	46.293	2.9	46.412	2.8	46.563	2.7	46.686
ITCODE31	3	46.720	2.9	46.885	2.8	46.874	2.7	46.692





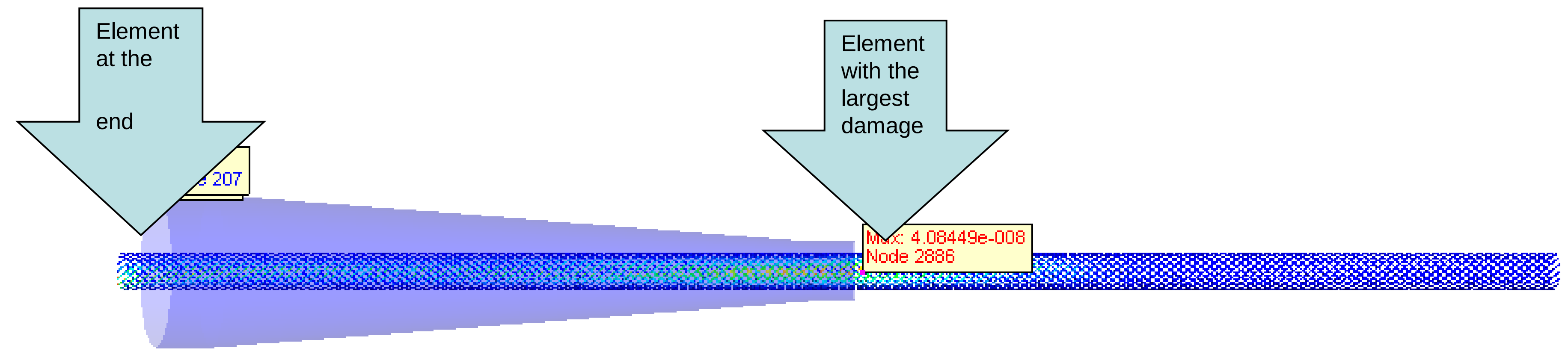
Summary and Further work

In this case analysis, the largest damage happens at the end of the bend stiffener (outside), this situation should not happen in a real case. So in the next step, larger longitudinal force (from 0.1MN to 0.5 MN) should be added, then get the largest damage and analysis the stress again,

Results and Discussion
Stress analysis and Fatigue

Look into the stress range ($\Delta\sigma_{ax}$, $\Delta\sigma_{my}$, $\Delta\sigma_{mz}$, $\Delta\sigma_{xx}$) at the end of the pipe and at the other side of the bending stiffener. Compare the stress range of the element where has the largest fatigue damage.

ITCODE 0



Gap (pitch length)	Element number	Section	Point	$\Delta\sigma_{xx}$	$\Delta\sigma_{ax}$	$\Delta\sigma_{my}$	$\Delta\sigma_{mz}$	Maximum damage
0	1002	1	2	187.328	168.353	1.922659	17.05214	$4.45883e^{-8}$
0.25	2709	1	2	165.216	163.464	7.01827	1.841331	$4.08449e^{-8}$
0.5	2776	1	3	164.797	163.498	7.42554	5.72821	$4.08692e^{-8}$
0.75	2861	1	3	162.784	162.455	6.76143	1.771977	$4.06779e^{-8}$
0	2608	1	3	176.169	168.353	1.922659	17.05214	$4.08419e^{-8}$
0.25	1002	1	2	165.5	162.176	1.747868	15.06827	$3.98942e^{-8}$
0.5	1002	1	2	150.936	149.533	1.537703	12.65842	$3.13334e^{-8}$
0.75	1002	1	2	136.003	135.191	1.386066	10.93032	$2.32109e^{-8}$

In this case, only the model with 0 pitch length gap got the largest damage at the left end of the pipe, the other models got the largest damage at the right end of the bending stiffener.
The largest damage gradually decreased as the gap length increased.

ITCODE 31

Gap (pitch length)	Element number	Section	Point	$\Delta\sigma_{ax}$	$\Delta\sigma_{my}$	$\Delta\sigma_{mz}$	$\Delta\sigma_{xx}$	Maximum damage
0	1100	1	5	160.872	9.44839	0.370619	161	$3.89466e^{-8}$
0.25	1105	1	5	160.872	9.29412	0.383044	161	$3.89467e^{-8}$
0.5	1110	1	5	160.872	9.12623	0.394321	161	$3.89466e^{-8}$
0.75	1115	1	5	160.871	8.94326	0.404249	161	$3.89464e^{-8}$
0	1001	1	5	139.343	3.05347	0.000356604	122	$1.70297e^{-8}$
0.25	1001	1	5	136.64	2.52834	0.000317916	124	$1.78163e^{-8}$
0.5	1001	1	5	134.419	2.09696	0.000259467	112	$1.31e^{-8}$
0.75	1001	1	5	132.867	1.794869	0.000213165	115	$1.45e^{-8}$

In this case, all the models got the largest damage at the node which is at the end of the bending stiffener.
The largest damage do not have big change as the gap length increase; while, the damage at the left end point has slightly decrease as the gap length increase.