POLITECNICO DI MILANO

POLO REGIONALE DI LECCO
MASTER OF SCIENCE IN MECHANICAL ENGINEERING

DESIGN OF SUBSEA JUMPER & SPOOL PIPELINES

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MASTER THESIS SUBMITTED BY
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ABSTRACT :

In the past 40 years, subsea systems have advanced from shallow water, manually operated systems in Water Depth less than 1,000ft (305m), into systems capable of operating via remote control at water depth from 1,000ft up to 10,000 ft (3,000m).

The design of the subsea components able to operate correctly in such extreme environment has become more and more complex because of the non-accessibility of the seabed. Multiple possibilities of locations and events have to be foreseen and tested.

This thesis project aims at developing FEA design tools to compute automatically design models and to check international standards for Jumpers and Spools subsea pipelines. This mission was conducted in the Flowline Design Departement of the company SAIPEM SA Eni in Paris as an internship project.

In this document, first of all, the usage of Jumpers and Spools among the subsea engineering system will be explained. Since those pipelines are usually designed in compliance with the international standards ASME B31.8 and DNV-OS-F101, a brief description of the different design load and stresses checks of those will be given.

Then the complete range of components of Jumpers and Spools as well as the design conditions to be taken into account will be detailed. The life cycle of those structures, starting from the installation to the long term operations are be considered in the design.

Eventually the Finite Element design spreadsheets developed will be explained. Both ABAQUS and AUTOPIPE software will be used to design Jumpers and Spools pipelines extracted from previous Saipem Eni projects. Verification and comparison of the results of stresses and reaction loads at the two bases will be used to validate the tool created for FE design of Jumpers and Spools.

Jumpers and Spools design requires the consideration of multiple displacements cases corresponding to the different tolerances (installation and metrology) and multiple loading cases corresponding to the life cycle loads. Moreover the design of such an adaptable structure should be made in different geometrical configurations since the correct dimensions are only known at the very last step of installation. Taking into account the complete range of load cases is necessary for the design of the Jumpers and Spools . That’s the reason why an automatic VBA tool generating the input FE files and post-processing the outputs is useful for the Flowline Design Departement of Saipem SA.

By reviewing the results obtained with the spreadsheets on both ABAQUS and AUTOPIPE, similar and comparable results are obtained, which indicates that models on both software are coherent. Safety margins ratios are computed and comply with international standards.

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ACKNOWLEDGEMENTS :

I would like to thank my kind company manager at SAIPEM SA, Engineer Simon Grevet for his full support throughout the entire duration of the project.

Special thanks to my supervisor at Politecnico di Milano, Professor Giorgio Previati who gave me the opportunity of attending the Advanced Design course at Lecco, which has been of great help to comprehend Finite Element Analysis.

Thoughts also go for parents, family and friends for their constant support.

1. INTRODUCTION

The introduction section deals with basics of subsea piping engineering in the oil and gas field. Spool and Jumper structures will be more deeply studied.

1.1 OVERVIEW OF SUBSEA PIPING STRUCTURES

The offshore oil and gas industry started in 1947 when Kerr-McGee completed the first successful offshore well in the Gulf of Mexico off Louisiana in 15 ft (4.6m) of water. The concept of subsea field development was suggested in the early 1970s by placing wellhead and production equipment on the seabed. The hydrocarbon produced would then flow from the well to a nearby processing facility, either on land or an existing offshore platform. This concept was the start of subsea engineering, and systems that have a well and associated equipment below the water surface are referred as subsea production systems.

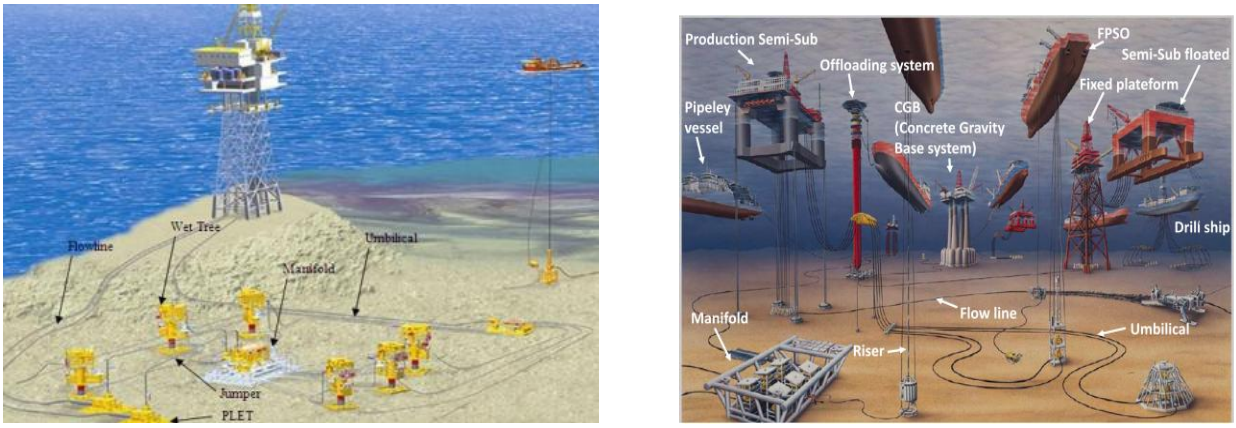


Figure 1. Typical subsea production systems

The extracted oil or natural gas is transported by pipeline under the sea before it rises to a processing facility. The development of new fields can either be initiated via long tie-back to an existing facility or by installing a new “stand-alone” facility. The top side stand alone facilities can be divided into four typical host facilities : Floating Production Systems (FPS), Tension Leg platforms (TLP), Jack-up platform and semi-submersible platforms.

-**Floating Production Systems (FPS)** : FP consist of large monohull structures, generally in the shape of ships, equipped with processing facilities.

-**Tension leg platforms (TLPs)** : TLPs are floating platforms tethered to the seabed so that most vertical movement are eliminated. TLPs are used in water depths up to 2000m.

-**Jack-up platforms**: Jack-up platforms are platforms that can be jacked up above the sea using legs that can be lowered. They are used up to around 150m water depth.

-**Semi-submersible platforms** : These platforms have buoyancy modules to cause the structure to float and stay upright. Those installations can be used in water depth from 60 to 3050m.

Figure 2. Typical offshore facilities

The subsea production system consists of all the components and pipelines that ensure the transport of the oil and gas from the well to the facility. The different mechanical structures involve in a subsea production system are:

1.1.1 Subsea Manifolds

The manifold, as shown as in Figure 3, is an arrangement of piping and/or valves design to combine, distribute, control, and often monitor fluid flow. The manifold may be anchored to the seabed with piles or skirts that penetrate the mudline. The numerous types of manifold range from a simple Pipeline End Manifold (PLEM/PLET) to large structures such as a subsea process system.

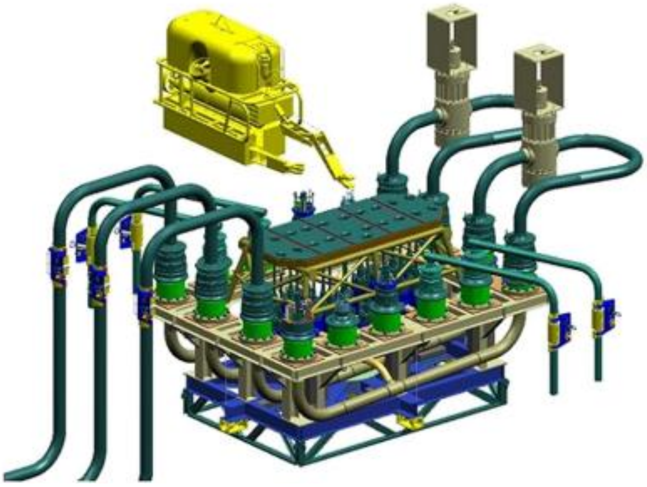


Figure 3. Subsea Manifold and ROV

1.1.2 Pipeline Ends and In-line Structures

As the oil/gas field developments move further away from existing subsea infrastructures, it becomes advantageous to consider a subsea tie-in of their export systems. This requires incorporation of pipeline end manifolds (PLEMS) at both pipeline ends to tie-in the system. A PLEM is used to connect rigid pipeline with other subsea structure, such as manifold or tree, through a jumper. It is also called Pipeline End Termination (PLET). Figure 4 shows a typical subsea PLET.

Figure 4. Subsea PLET

1.1.3 Subsea wellheads

Wellhead is a general term used to describe the pressure-containing device at the surface of an oil well that provides the inferface for drilling, completion, and testing of all subsea operation phases. Subsea wells can be either satellite wells or clustered wells.

- *Satellite Wells* are individual and remotely located to other wells. The primary advantage of satellite well is the flexibility of individual well exploitation. The production and treatment of each well can be optimized to the maximum.

- *Clustered Wells* mean the gathering of several wells and the sharing of common facilities by those wells. This will then require fewer flowline and umbilicals, thus reducing costs. Clustered systems, however, introduce the need for subsea chokes to allow individual well control. Moreover the drilling operations of one well can interrupt production from the other.

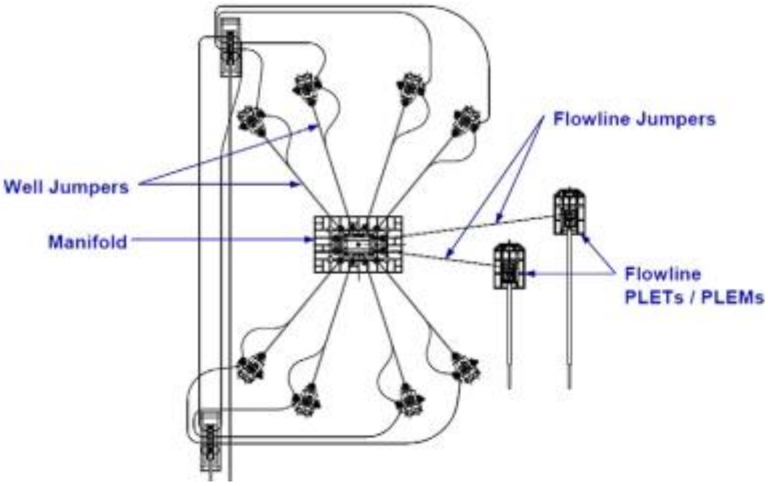


Figure 5. Typical manifold cluster layout

Artificial lift methods are used to continuously remove liquids from a liquid loaded gas well. The lack of energy in a reservoir can affect the flow rate of oil, gas or water. Using this method, energy is transferred downhole and the fluid density in the wellbore is reduced.

1.1.4 Subsea Trees

The subsea production tree is an arrangement of valves, pipes, fittings, and connections placed on the top of a wellbore. Orientation of the valves can be vertical or horizontal and operated whether by electrical or hydraulic signals or manually by a driver or Remote Operated Vehicle (ROV).

1.1.5 Umbilical systems

An umbilical is bundled arrangement of tubing, piping, and/or electrical conductor in an armored sheath. It is used to transport control fluid and electrical current necessary to control the facilities. Dedicated tubes in an umbilical are used to monitor pressures and inject fluids from the host facility to critical areas within the subsea production equipments.

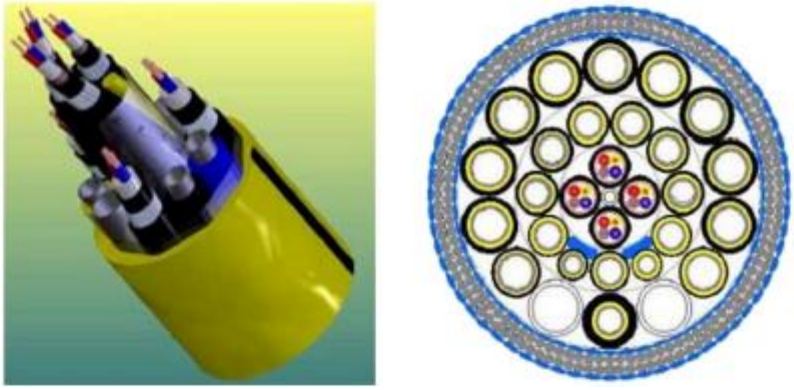


Figure 6. Subsea steel umbilicals

1.1.6 Production risers

The production riser is the portion of the flowline that resides between the host facility and the seabed adjacent to a host facility. Risers can be flexible or rigid. Those structure enable the rise of the production fluids to the surface facilities.

1.1.7 Subsea pipelines

Subsea flowlines are the subsea pipelines used to connect a subsea wellhead with a manifold or the surface facility. They may transport petrochemicals, lift gas, injection water and chemicals. A distinction can be made between the infield pipelines (typical range of 4”/12”) and the export pipelines that export the product from the field to onshore and to another facility (typical range 16”/36”). The flowlines may be made of flexible pipe or rigid pipe.

Subsea pipelines are increasingly required to operate at high pressures and temperatures. The higher pressure condition results in the technical challenge of providing a higher material grade of pipe for and the HT will cause the challenges of corrosion, down-rated yield strength, and insulation coatings. Flowlines will be subjected to high effective axial compressive force due to the high fluid temperature and internal pressure causing expansion which is partially restrained by soil friction/in-line structures. Consequently, in the design process, the expansions of the lines have to be considered and propagated to the adjacent structures. Jumpers and Spools pipes are specially conceived to accommodate such expansions, thus preventing the propagation of the displacement to all the structures.

1.1.8 Jumpers & Spools

A Spool is a prefabricated short pipe connector used to transport production fluid between two subsea components. A Jumper is a Spool with vertical geometry either in 2D/3D that usually presents floatability (no contact with the seabed).

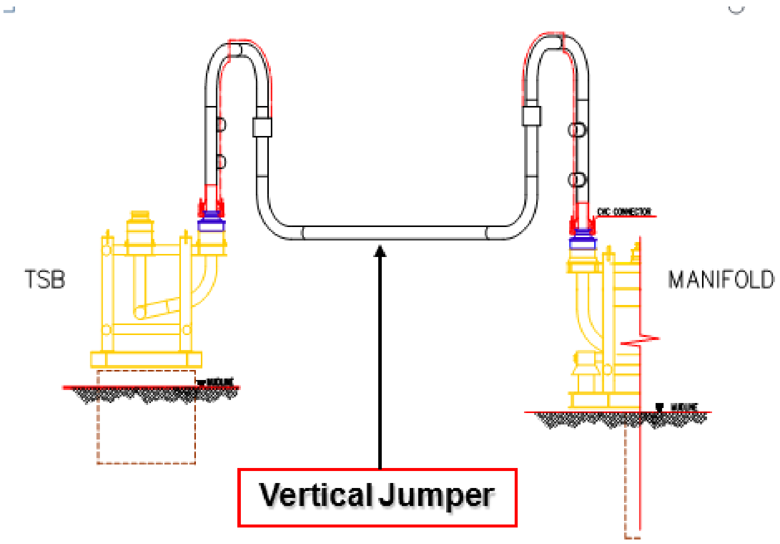


Figure 7. Vertical jumper

Such pipes are designed to accommodate installation tolerances and expansions of production lines. Jumpers and Spools primary purpose is to compensate the installation misalignments and line expansions during operations. Indeed those structures are the last equipment installed at the seabed and their special geometry provides flexibility and adaptability.

Economically speaking, the most critical issue about Jumpers and Spools is the very short time available for fabrication works. The exact required dimensions of the structure are known only once all the other subsea production systems have been installed and metrology survey conducted. Since offshore installation implies high cost and involves expensive boats and crews, the fabrication time has to be controlled. That is the reason why studies of possible design options and pre-fabrication are important.

It is essential to understand that most subsea structures are built onshore and transported to the offshore installation site. The installation includes three phases: lowering, landing and locking with the other structures.

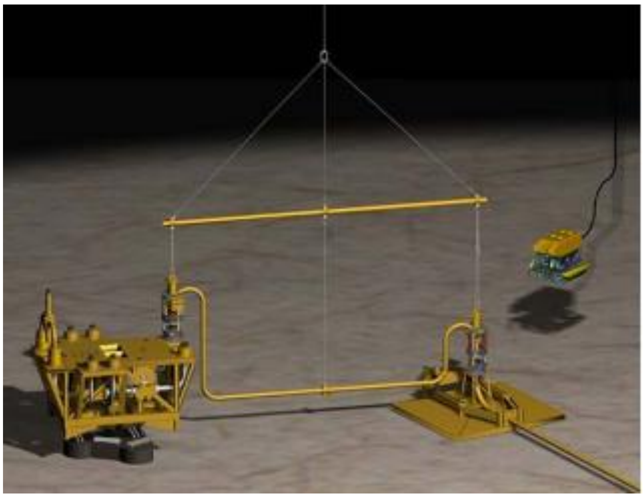


Figure 8. Rigid jumper installation

However due to the remote control operations, the exact positioning at the seabed is a challenge. That’s the reason why, installation target boxes are been considered. As a result Jumper design will consider the complete range of possible configurations of the structures i.e. different lengths and angles. Indeed Jumpers and Spools connect two structures thus accommodating two uncertainties of installation positioning:

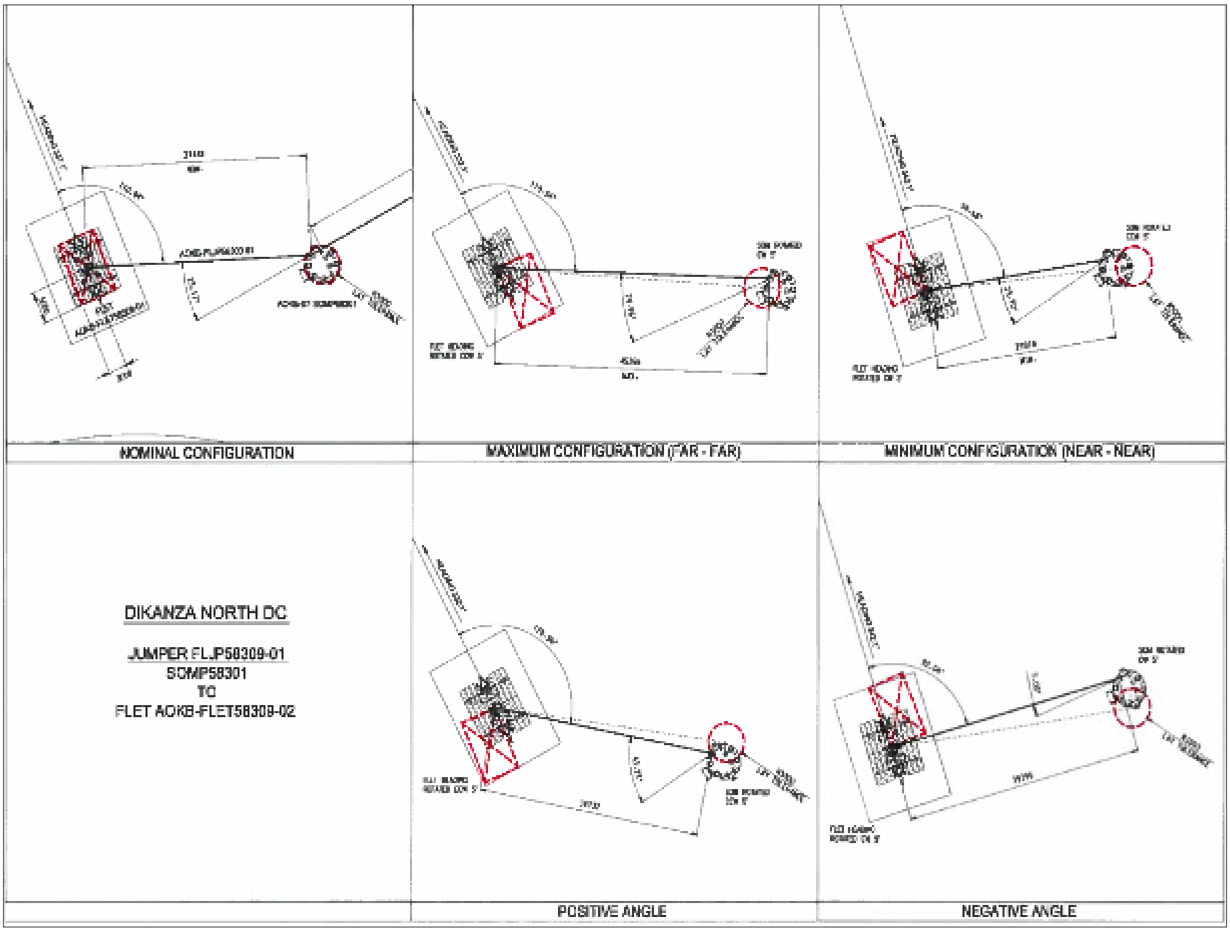


Figure 9. Installation target boxes of two structures link by a Jumper

The strength studies of Jumpers & Spools require taking into account the geometry, the connecting ends, environmental loads and influences of the operating fluid. Thus Finite Element Analysis software are used to conduct appropriate design checks.

International codes and standards are being applied for all the subsea systems. The main objective of those codes is to establish minimum requirements that are necessary for safe construction and operation. The client approval and design check of the subsea equipment are based on the adequacy with the standards (ASME, DNV). As a consequence a piping engineer must have a good understanding of the offshore section of those codes.

1.2 PURPOSE OF THE THESIS

The aim of this thesis is to study and model Jumpers & Spools for multiple projects developing automatic modeling FEA tools and post-processing in compliance with ASME B31.8. and DNV OS-F101 codes. The available software to model and analysis the structures are Bentley AUTOPIPE V8i Plus and ABAQUS v.6.12.1. The codes and standards should be respected and both FEA sofware should carry on design calculations.

The difference between the two programs is that since ABAQUS is a general FEM software, the program is not able to perform directly the checks according to ASME B31.8 or DNV. Consequently calculations will have to be performed starting from the force and moment outputs of ABAQUS. However AUTOPIPE can present the outputs directly according to the standards in the case of ASME checks (Hoop stress, Longitudinal stress, Combined stress), but post processing is still necessary for DNV checks.

The model philosophy is to generate the Jumper and Spool geometries with Pipes and Bends elements by automatic VBA code. All the components of those structures will be considered (connectors, coatings, claddings). All the elements are not exactly modeled but rather included in the design (for example coating and cladding are just represented by extra weight). Additionally the external loads (pressures, waves, buoyancy modules) on the structures as well as the imposed displacements at the extremities will be applied. Stresses and Reactions forces are to be summarized in order to perform the standard stress checks and connector load limits. Moreover the maximum displacements have to be assessed making available the seabed clearance of the structures.

Jumpers & Spools design requires to test multiple geometrical configurations (Near-Near, Far-Far, Nominal, Positive angle, Negative angle) and multiple life-cycle steps (as landed, stroking, hydrotest, leak test, design, operating, shut-down, retrieval). Consequently tools developed are focusing on the “self-running” of the modeling and checking of all the configurations. The main objective of such tool is to increase the efficiency and reliability of Jumper & Spool design procedures.

Both M-shaped Jumpers and three dimensional (3D) Spools will be designed and post processed. The soil contact, the buoyancy forces and the wave loads will make the design process more complex. In the next chapters, Jumpers and Spools will be modeled in details with both software and the results will be compared to ensure their validity.

The project has been possible thanks to a tight planning of the different development steps. Indeed the approach of the subsea engineering and its understanding was the first required step of the study. Researching and reading the available documents about the design of subsea structures and redacting a technical memo that deals with the design of Jumpers and Spools represented the first task of the project.

Creating coherent Abaqus models of Jumpers and Spools have been the second step of the project. Autopipe analysis have also been conducted in parallel in order to build comparison grounds. The post processing of both the FEA models has shown similarities. It has been the basis for the comprehension of the correct design of Jumpers and Spools in terms of geometry and loads.

The development of automated spreadsheets generating input FEA files for models on both Abaqus and Autopipe and post-processing the outputs constitutes the very main innovating part of the project. Indeed the advantages of VBA coding have been exploited thus enabling the user of the newly developed spreadsheets to design multiple Jumpers (configurations) in multiple load cases (As Landed, Hydrotest, Leak Test, Operating, Design and Shut Down).

At first, focus has been set on the design of vertical M-shaped Jumpers. Three spreadsheets which generate models with buoyancy modules and complete parameterized conditions (dimensions, pressure and temperature, loads) and post-process the outputs, have been created. The validation of those spreadsheets is being carried on internally in the Flowline Design Department of Saipem Eni, Paris.

The Second step aims at improving the previously developed spreadsheets for M-shaped vertical Jumpers into 3D modeling of Jumpers/Spools. Very conclusive solutions for the modelling of 3D Jumpers have been reached during the thesis project and first versions of input spreadsheets have been issued. Testing and approvals of those spreadsheets are currently being conducted in the design department.

2. STATE OF THE ART

2.1 BASIC COMPONENTS OF JUMPERS & SPOOLS

The project has the objective of modelling Jumpers and Spools of subsea projects and to analyze those structures on FEA software. In order to correctly define those pipelines, it is necessary to understand all different types of Jumpers and Spools that can be encountered and their components.

2.1.1 Jumper & Spool types

A typical jumper consists of two ends connectors and a pipe between the two connectors. If the pipe is a rigid pipe, the jumper is a rigid jumper. If the pipe is flexible, the jumper is a flexible jumper. In this thesis only rigid jumpers have been studied.

Jumper configurations are dictated by design parameters, interfaces with subsea equipment, and the different modes in which the jumper will operate. Two types of configurations can be distinguished: the vertical tie-in and the horizontal tie-in.

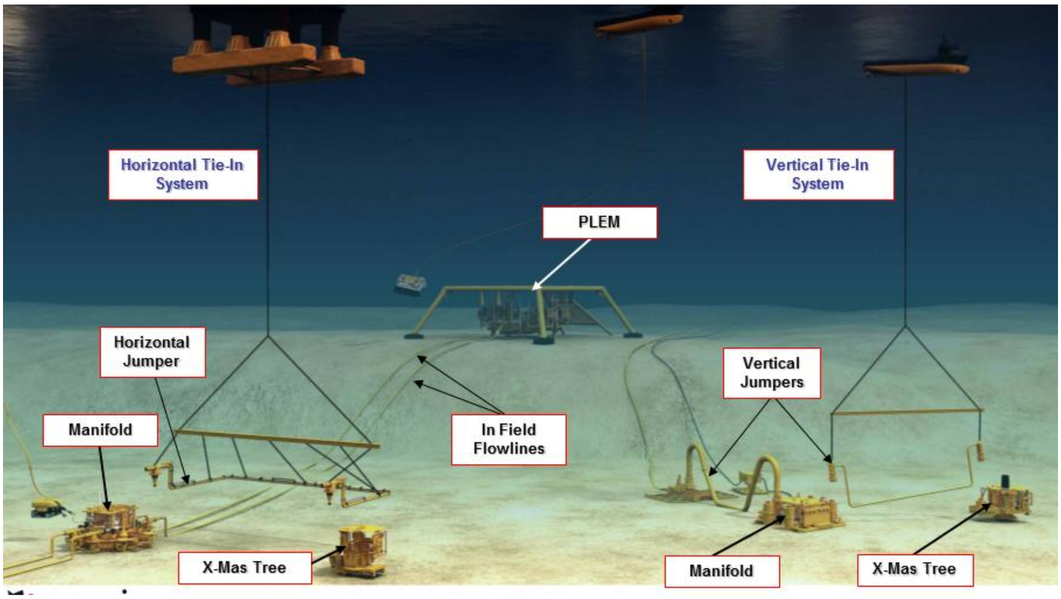


Figure 10. Two types of subsea Jumpers

2.1.1.1 Vertical Tie-in

Vertical jumpers, are typical vertical tie-in systems and use mechanical collet connectors at each end. The connection at the extremities of the jumper pipe is made possible thanks to connector hub.

The stroking and connection are carried out by the connector itself, or by ROV (Remote Operated Vehicle)-operated connector actuation tool (CAT) as shown in Figure 11. Advantages of vertical configuration are the faster connection process and the less demanding requirement of pipe length. However the complex transportation of those structures and the high weather dependence installation with the required advanced connector technology may counter balance the advantages.

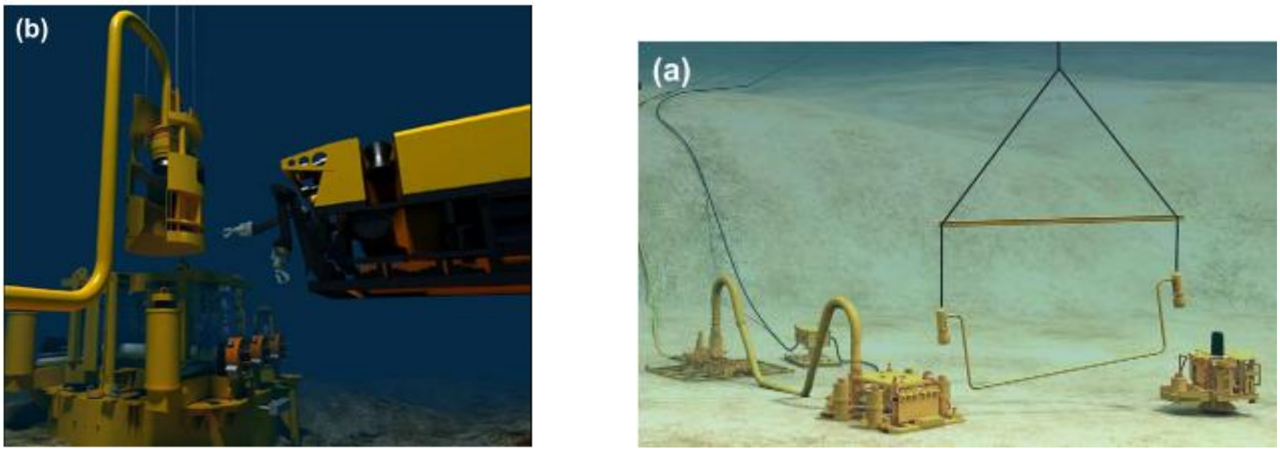


Figure 11 a & b. Vertical Tie In Jumper Installation

2.1.1.2 Horizontal Tie-in

Horizontal spools usually lay on the seabed and use bolted joints connections. The reduced size of those structures is an asset for the installation vessels. Figure 12 shows an horizontal tie-in system highlighting the stability of the lowering step. The installation procedure is more complex than vertical jumpers. The tie-in may be made up by clamp connectors operated from a tie-in tool, by integrated hydraulic connectors operated through a ROV, or by non-hydraulic collet connectors with assistance from a CAT and ROV.

The installation procedure for a horizontal tie-in system is illustrated in Figure 13 and described here:

- The spool of the horizontal tie-in system hooked up to a spreader beam is deployed and lowered to within a few meters above the target areas on the subsea structures as shown in Figure 13-a.

- The spool is lowered until the stab on the first termination head enters the stab receptacle on the tie-in porch as shown in Figure 13-b. The second termination head will align horizontally as the spool continues to be lowered until the stab enters the stab receptacle and lands on the tie-in porch.

- The CAT is landed and locked on the first termination head by the ROV as shown in Figure 13-c.

- The termination head is leveled and locked in the horizontal position. The protection caps are removed from the connector and the inboard hub as shown in Figure 13-d.

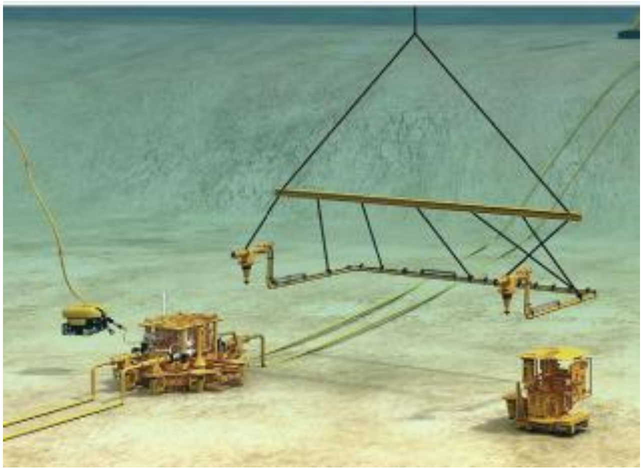


Figure 12. Horizontal Tie In Jumper

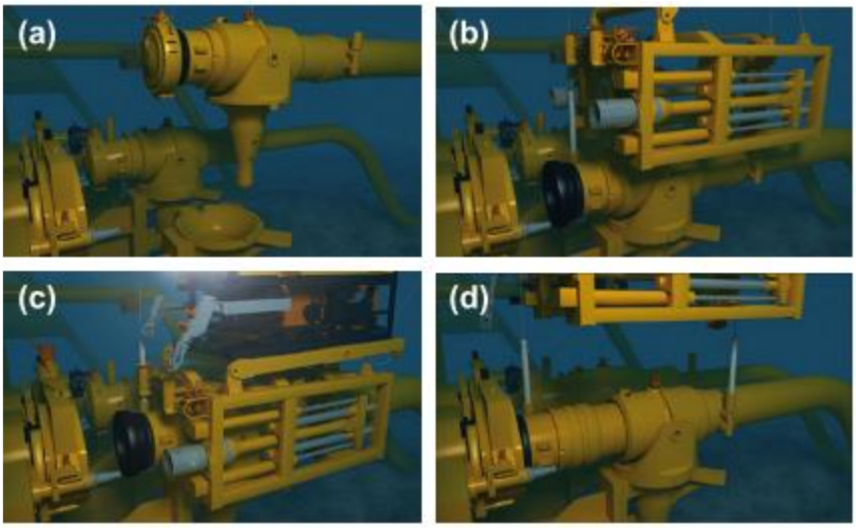
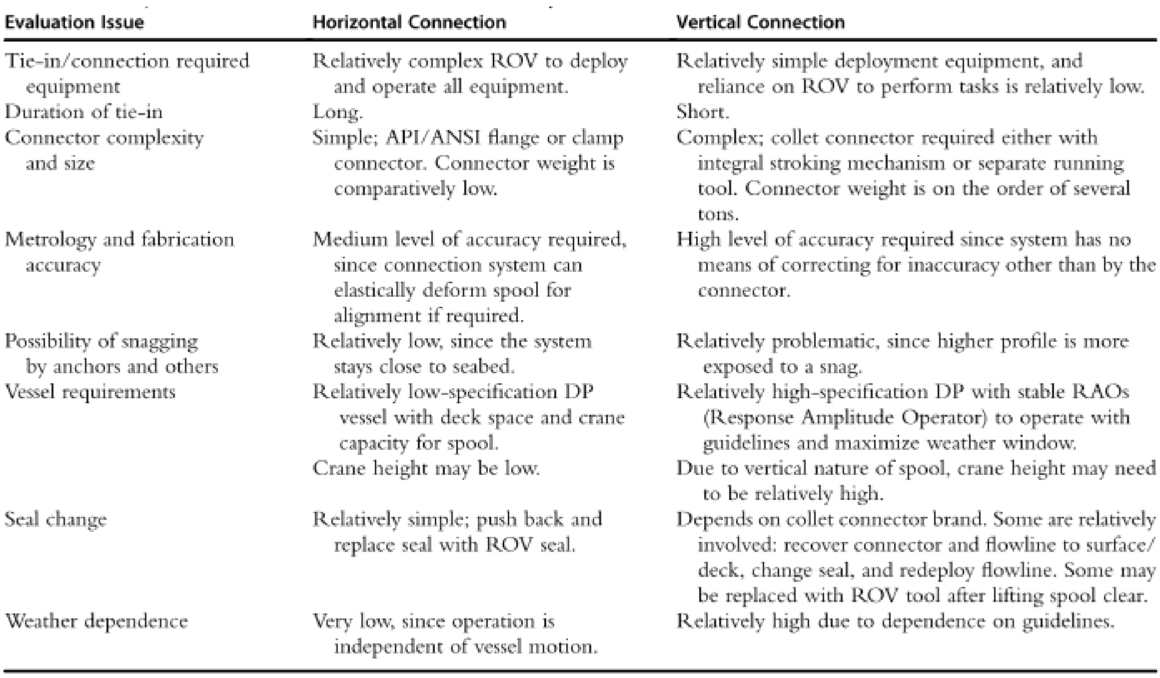


Figure 13. Installation Procedure for a Horizontal Jumper

The following table summarizes a comparison between horizontal and vertical tie-in.



Evaluation Issue	Horizontal Connection	Vertical Connection
Tie-in/connection required equipment	Relatively complex ROV to deploy and operate all equipment.	Relatively simple deployment equipment, and reliance on ROV to perform tasks is relatively low.
Duration of tie-in	Long.	Short.
Connector complexity and size	Simple; API/ANSI flange or clamp connector. Connector weight is comparatively low.	Complex; collet connector required either with integral stroking mechanism or separate running tool. Connector weight is on the order of several tons.
Metrology and fabrication accuracy	Medium level of accuracy required, since connection system can elastically deform spool for alignment if required.	High level of accuracy required since system has no means of correcting for inaccuracy other than by the connector.
Possibility of snagging by anchors and others	Relatively low, since the system stays close to seabed.	Relatively problematic, since higher profile is more exposed to a snag.
Vessel requirements	Relatively low-specification DP vessel with deck space and crane capacity for spool.	Relatively high-specification DP with stable RAOs (Response Amplitude Operator) to operate with guidelines and maximize weather window.
	Crane height may be low.	Due to vertical nature of spool, crane height may need to be relatively high.
Seal change	Relatively simple; push back and replace seal with ROV seal.	Depends on collet connector brand. Some are relatively involved: recover connector and flowline to surface/deck, change seal, and redeploy flowline. Some may be replaced with ROV tool after lifting spool clear.
Weather dependence	Very low, since operation is independent of vessel motion.	Relatively high due to dependence on guidelines.

Both types of tie-in can be encountered and models for both are developed. The geometry generating tools will be modified accordingly. The type of Jumper/Spool will have significant impact on adjacent structures: the connectors, settlement and interfaces will be different. The horizontal type would impose coordinate transformation at the extremities to deliver correct reaction loads (forces and moments). Indeed the reactions loads are part of the check demanded by the design procedures since connector manufacturers give maximum allowable loads that can be applied on the connector hubs.

2.1.2 Connectors

The connector should be used at the end of the jumper piping to lock and seal the mating hub on the connector receiver. The connector should be equipped with the following components:

(1) a mechanism (e.g., collet, fingers, or dogs) designed to resist lateral and longitudinal forces that may be encountered in the process of aligning and final lowering, prior to makeup of the connection (the connector is designed to accommodate the design loads);
(2) metal-to-metal seal surfaces inlaid with corrosion resistant alloy; the seal surfaces shall be relatively insensitive to contaminants or minor surface defects and maintain seal integrity in the presence of the maximum bending moments and/or torsional moments;

(3) a metal seal with an elastomeric backup capable of multiple makeups;

(4) mechanical position indicators to indicate lock/unlock operations that are clearly readable by an ROV;

(5) a mechanical release override or a hydraulic secondary release system.

The connectors will be modelled by a hub-pipe with rigid properties. Indeed the connector hub can be considered much more rigid compared to the jumper pipe. Moreover the submerged weight of the connector will be applied at the hub middle length. Pup piece length can also be added in the design model as an extra pipe length with similar properties to the jumper pipe.

In both models developed for Abaqus and Autopipe, the length of the hub and the pup piece are parameterized. Indeed each project will present a different configuration.

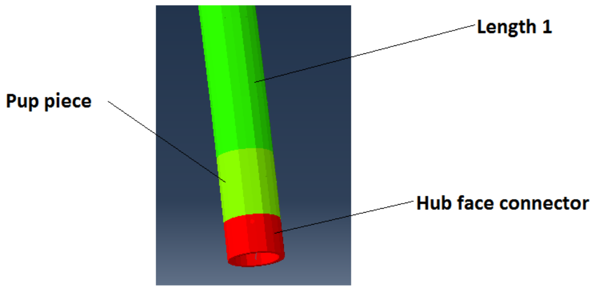


Figure 15. Abaqus model of the connector extremity

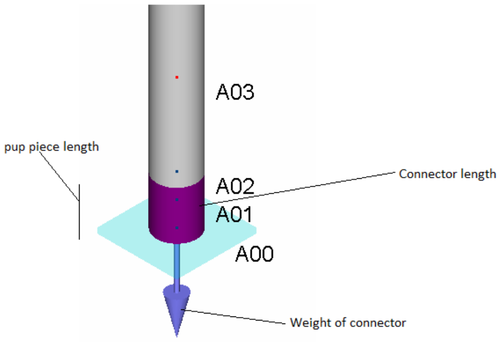
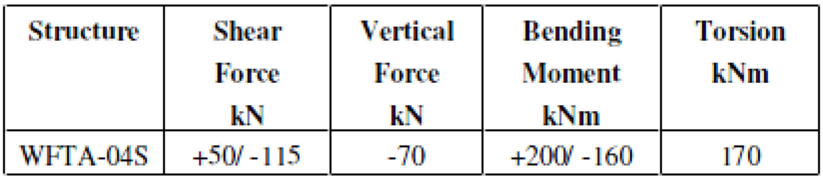


Figure 14. Autopipe model of the connector extremity

The connectors have allowable loads. Indeed the envelope values corresponding to maximum shear force, vertical force, bending moment and torsion on the connector have to be respected in compliance with the manufacturer specifications. Here below is an example of connector capacities for a CAMERON 12" connector.



Structure	Shear Force kN	Vertical Force kN	Bending Moment kNm	Torsion kNm
WFTA-04S	+50/ -115	-70	+200/ -160	170

Table 1. Example of connector load capacities

2.1.3 Pipe Material

Pipe steels must perform in a harsh environment, subject to the many corrosive and erosive actions of the sea, under dynamic cyclic and impact conditions over a wide range of temperatures. Thus, special criteria and requirements are imposed on the material qualities and their control. A pipeline steel must have high strength while retaining ductibility, fracture toughness, and weldability.

-Strength is the ability of the pipe steel (and welds) to resist the longitudinal and transverse tensile forces imposed on the pipe.

-Ductibility is the ability of the pipe to absorb overstressing by deformation.

-Toughness is the ability of the pipe material to withstand impacts or shock loads.

-Weldability is the ability to ease the production of quality welds and heat-affected zones of adequate strength and toughness.

For submarine pipelines, the prime factor driving the need for good weldability is economic. The faster the pipe can be welded, the faster it can be installed and the shorter the period of use of lay barge (high cost associated with lay barge use).

The steel used to form pipe joints are low carbon-manganese steels. This composition is offering the best comprise in terms of strength, reduction in tonnage and weldability. Table 7 below shows the typical strengthening processes for API 5L type pipeline steel with 1.5% manganese.

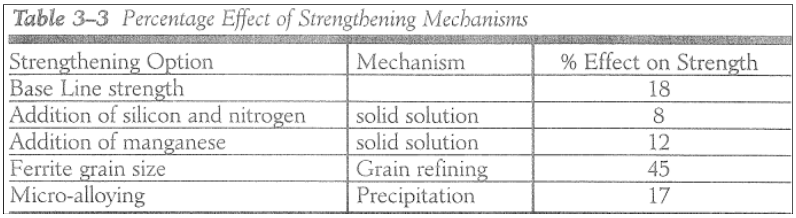


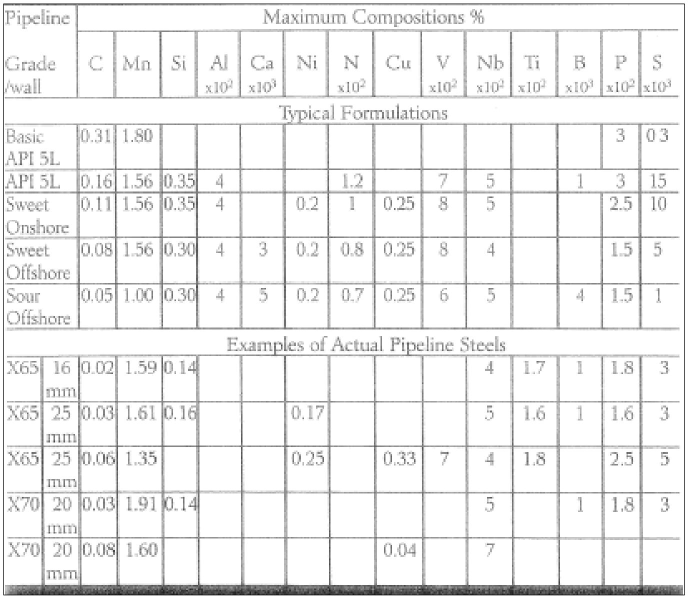
Table 3–3 Percentage Effect of Strengthening Mechanisms

Strengthening Option	Mechanism	% Effect on Strength
Base Line strength		18
Addition of silicon and nitrogen	solid solution	8
Addition of manganese	solid solution	12
Ferrite grain size	Grain refining	45
Micro-alloying	Precipitation	17

Table 2. Percentage Effect of Strengthening Mechanism

The higher strength grades are microalloyed and may be referred to as high-strength low-alloy (HSLA) steels. The pipe joints for oil and gas will conform to the American Petroleum Institute API Specification 5L.

The API 5L identifies the steel grade by the yield strength as X65 where the number refers to the yield strength in thousands of pounds per square inch i.e. grade API5LX65 has a yield strength of 65 psi or 448 MPa. The typical composition of pipeline steels is given below:



Pipeline Grade /wall		Maximum Compositions % C	Mn	Si	Al x10^2	Ca x10^3	Ni	N x10^2	Cu	V x10^2	Nb x10^2	Ti x10^2	B x10^3	P x10^2	S x10^3
Typical Formulations															
Basic API 5L		0.31	1.80											3	0 3
API 5L		0.16	1.56	0.35	4			1.2		7	5		1	3	15
Sweet Onshore		0.11	1.56	0.35	4		0.2	1	0.25	8	5			2.5	10
Sweet Offshore		0.08	1.56	0.30	4	3	0.2	0.8	0.25	8	4			1.5	5
Sour Offshore		0.05	1.00	0.30	4	5	0.2	0.7	0.25	6	5		4	1.5	1
Examples of Actual Pipeline Steels															
X65	16 mm	0.02	1.59	0.14							4	1.7	1	1.8	3
X65	25 mm	0.03	1.61	0.16			0.17				5	1.6	1	1.6	3
X65	25 mm	0.06	1.35				0.25		0.33	7	4	1.8		2.5	5
X70	20 mm	0.03	1.91	0.14							5		1	1.8	3
X70	20 mm	0.08	1.60						0.04		7				

Table 3. Typical Composition of Mn-Steels

When selecting the correct steel material for a pipeline special attention should be given to the following parameters of the steel:

Minimum yield strength
Minimum ultimate strength
Minimum elongation at rupture
Notch toughness at low temperatures
Through-thickness properties
Weldability
Fatigue endurance
Chemical composition

The American Petroleum Institute (API), the American Institute for Steel Construction (AISC), and Det Norske Veritas (DNV) include documents with classification of steel materials as well as limitations on their use.

2.1.4 Pipe components

The Outside diameter (OD) of the jumper pipe should be known. Usually indicated in inch it should be converted into mm if required. The bend radius of the structure is also an important parameter as it should be well designed to comply with the applied stress but also to assure correct flow of the product content. Moreover the bend radius is constrained by the circulation of testing/cleaning devices (Pigs) that travel the pipe.

In the bend sections, the thickness is usually reduced because of the fabrication process that consists in bending a formerly straight pipe. When tubing is bent, the wall of the outside edge of the curve stretches and becomes thinner, while the wall of the inside edge compresses and becomes thicker. If the walls of tubing are too thin to begin with, the outside edge will break, kink, or deform. Consequently a bend thinning percentage should be applied to the wall thickness in the calculation of the stress in the bend. The Ovality induced by the fabrication of the bended pipe should also be considered.

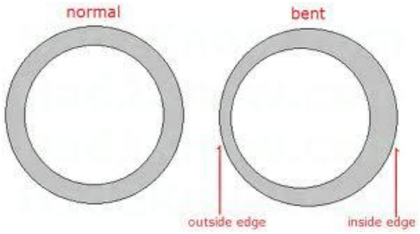


Figure 16. Wall thickness with bend thinning

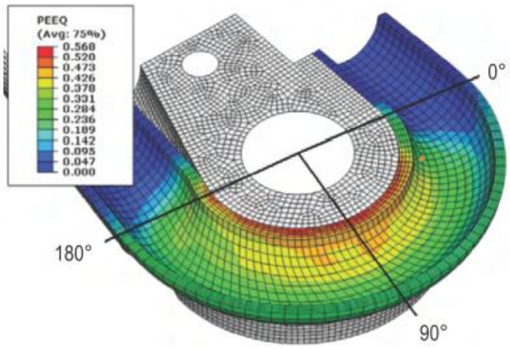


Figure 17. Bend tubing manufacturing

The Wall Thickness (WT) is also determined according to the difference of pressure applied to the pipe between outside and inside. The Corrosion Allowance (CA) is an estimated corrosion thickness that could be deducted from the nominal thickness in case of corrosion. The nominal thickness (WT) is theoretically known however a fabrication tolerance should be taken into account.

Coating of the pipe is carried on to ensure excellent resistance to corrosion, abrasive wear and tear. Three Layer Polypropylene Coating (3LPP) is usually used as anti-corrosion coating. The weight of the coating must be taken into account in the design of the Jumpers and Spools. Here below is an example of the 3LPP coating data.

Property	**Unit**	**Water Injection 6" Jumper**
Coating Material	-	3LPP
Coating Thickness	mm	3
Coating Density	kg/m^3	942

Table 4. Coating 3LPP

Insulation thickness required to prevent hydrate formation during operations (obstruction of the flow) and to maintain a certain fluid temperature may also be part of the properties of the pipe.

Figure 18. Epoxy coating

Cladding can sometimes be used in case of particularly severe corrosive conditions of the product content. It is a coating of high-cost corrosion resistant alloys applied on the pipe inner surface. Weld overlay cladding of carbon steel offers a wide choice of processes and flexibility to protect an almost infinite range of component shapes and sizes, with an equally wide range of base materials and cladding alloys.

Figure 19. Pipe Cladding

The drawing below represents a cross-section of the Jumper/Spool pipe :

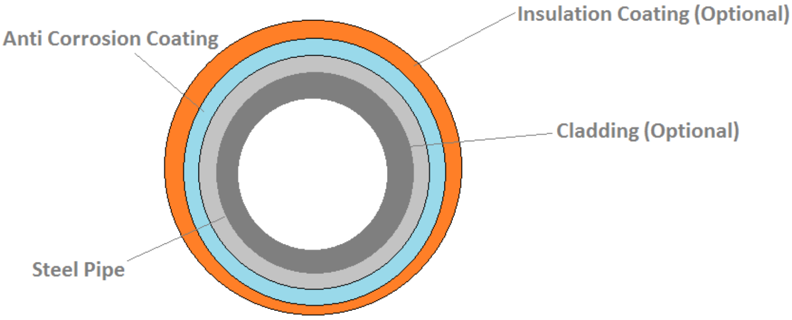
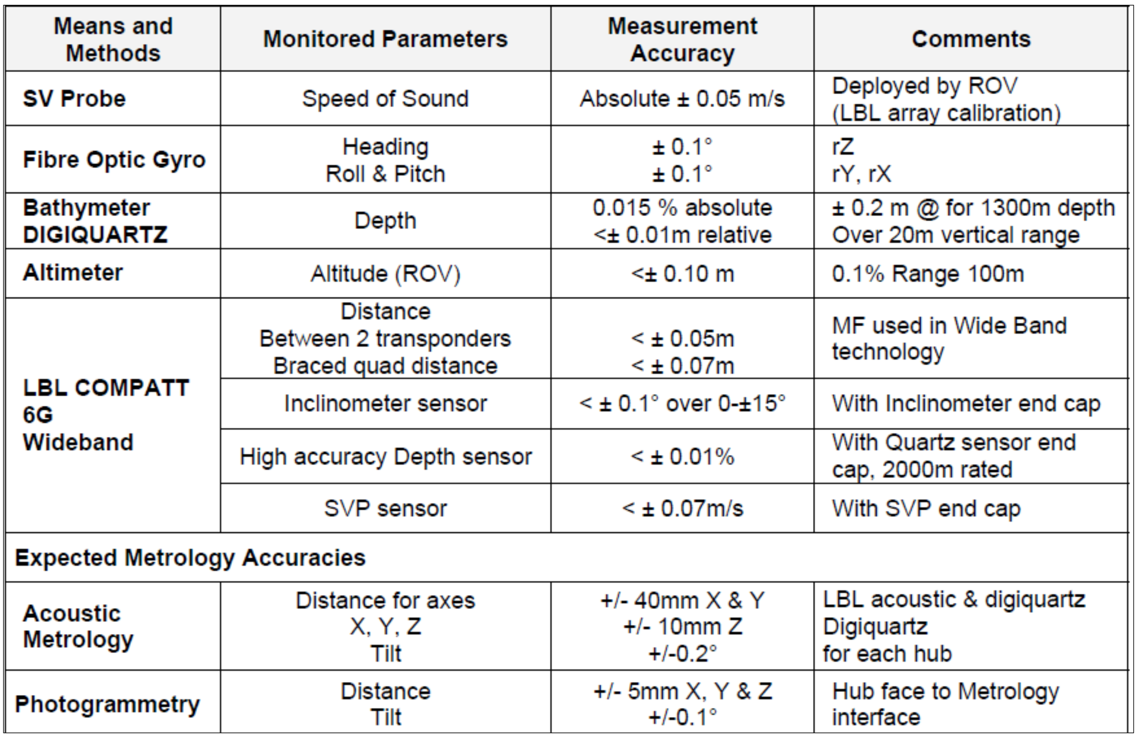


Figure 20. Pipe Cross Section

The pipe will be submitted to different loading conditions (variation in internal pressure, product content and related density). Indeed the installation steps during which the jumper is flooded needs to be studied. Then testing phases of the installation with water content but at higher pressure are part of the process. Finally operating conditions with product content happen. The design process should also be aware of the exceptional possible shut down state (no content is left in the pipe) and retrieval operations.

2.2 METROLOGY

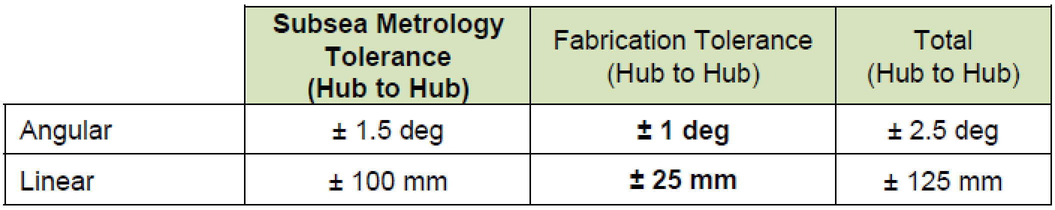
The structures are equipped with transponders. During the survey campaign, after installation of structures to connect with jumpers (PLETs, FLETs, SOMs, Manifolds), precise positioning of the equipment is measured. From the vessel, we measure the exact coordinates and orientation of the installed hubs. Several measuring techniques are used, as shown in the table below, the accuracies of the results are also taken into account.



Means and Methods	Monitored Parameters	Measurement Accuracy	Comments
SV Probe	Speed of Sound	Absolute ± 0.05 m/s	Deployed by ROV (LBL array calibration)
Fibre Optic Gyro	Heading Roll & Pitch	± 0.1° ± 0.1°	rZ rY, rX
Bathymeter DIGIQUARTZ	Depth	0.015 % absolute <± 0.01m relative	± 0.2 m @ for 1300m depth Over 20m vertical range
Altimeter	Altitude (ROV)	<± 0.10 m	0.1% Range 100m
LBL COMPATT 6G Wideband	Distance Between 2 transponders Braced quad distance	< ± 0.05m < ± 0.07m	MF used in Wide Band technology
	Inclinometer sensor	< ± 0.1° over 0-±15°	With Inclinometer end cap
	High accuracy Depth sensor	< ± 0.01%	With Quartz sensor end cap, 2000m rated
	SVP sensor	< ± 0.07m/s	With SVP end cap
Expected Metrology Accuracies			
Acoustic Metrology	Distance for axes X, Y, Z Tilt	+/- 40mm X & Y +/- 10mm Z +/-0.2°	LBL acoustic & digiquartz Digiquartz for each hub
Photogrammetry	Distance Tilt	+/- 5mm X, Y & Z +/-0.1°	Hub face to Metrology interface

Table 5. Measuring Techniques and Accuracy

For the design process an angular and a linear tolerance which include both the metrology tolerance and the fabrication tolerance are defined.



	Subsea Metrology Tolerance (Hub to Hub)	Fabrication Tolerance (Hub to Hub)	Total (Hub to Hub)
Angular	± 1.5 deg	**± 1 deg**	± 2.5 deg
Linear	± 100 mm	**± 25 mm**	± 125 mm

Table 6. Measurement tolerances

Typical drawings obtained after metrology enable the designer to collect data about the length and orientation of the hubs.

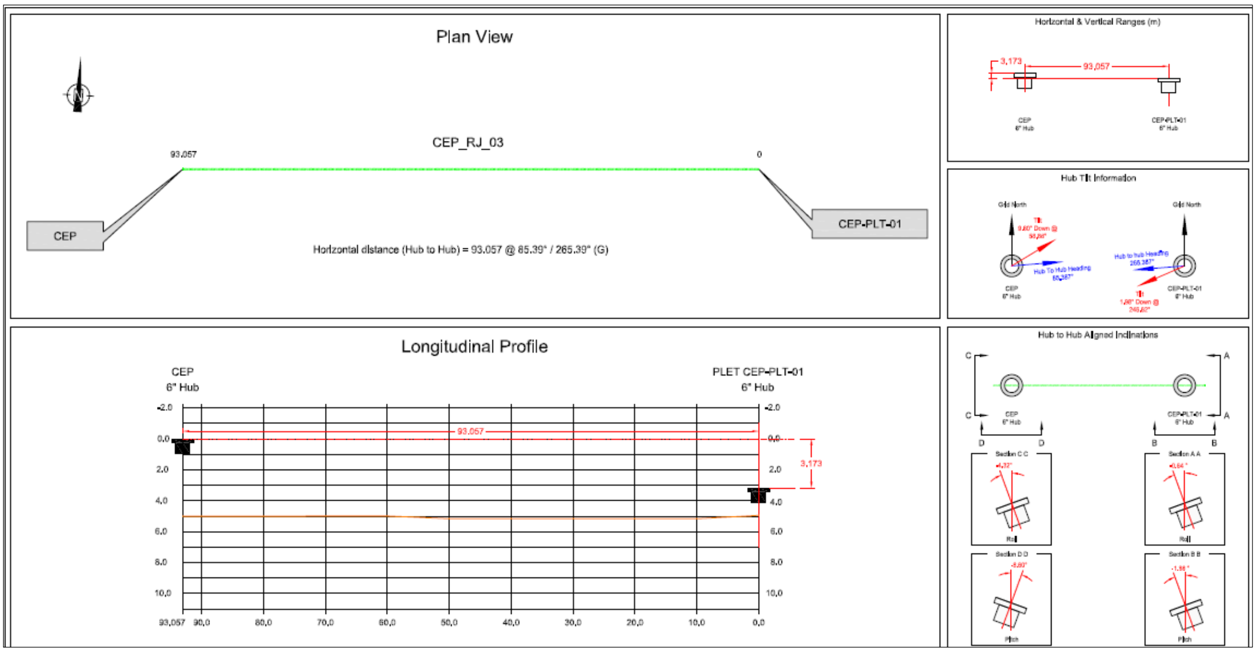


Figure 21. Metrology drawing

The interesting data to extract from this drawing are :

- Total Length between the 2 hubs and elevations.

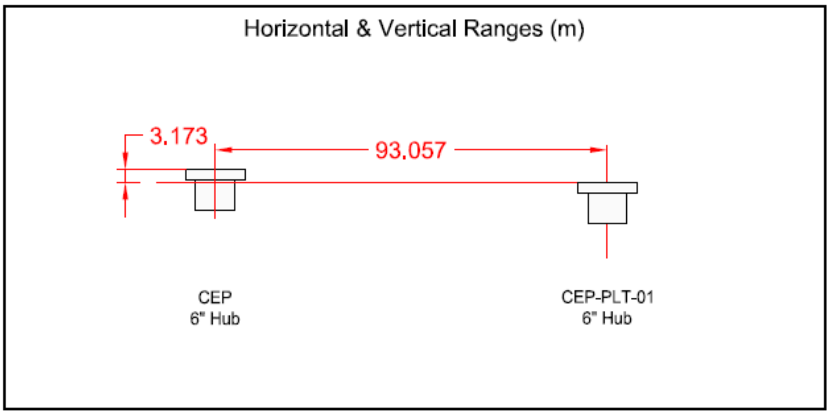


Figure 22. Total length and elevation

-The headings of each hub.

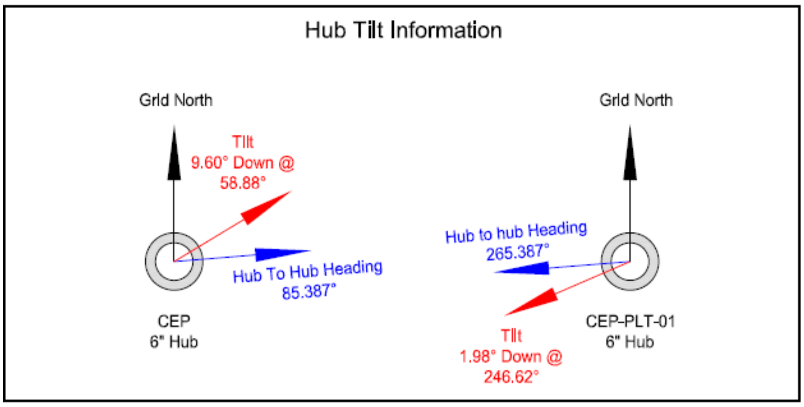


Figure 23. Hub orientation

2.3 LIFE CYCLE

The following flowchart represents the different steps in the jumper life cycle.

Onshore Hydrotest
Landing
Strocking
Offshore Hydrotest
Offshore Leak Test
Operating
Retrieval

Content density, pressure conditions, temperature conditions will vary during the steps described above. Consequently the model that has to be created is going to consider each of those life cycle steps.

2.3.1 Transportation & Installation of Jumpers and Spools

The Jumpers and Spools are pre-fabricated. They are usually composed of:
- 2 connectors with their pup-pieces
- 2 vertical U-shape parts
- 2 horizontal parts

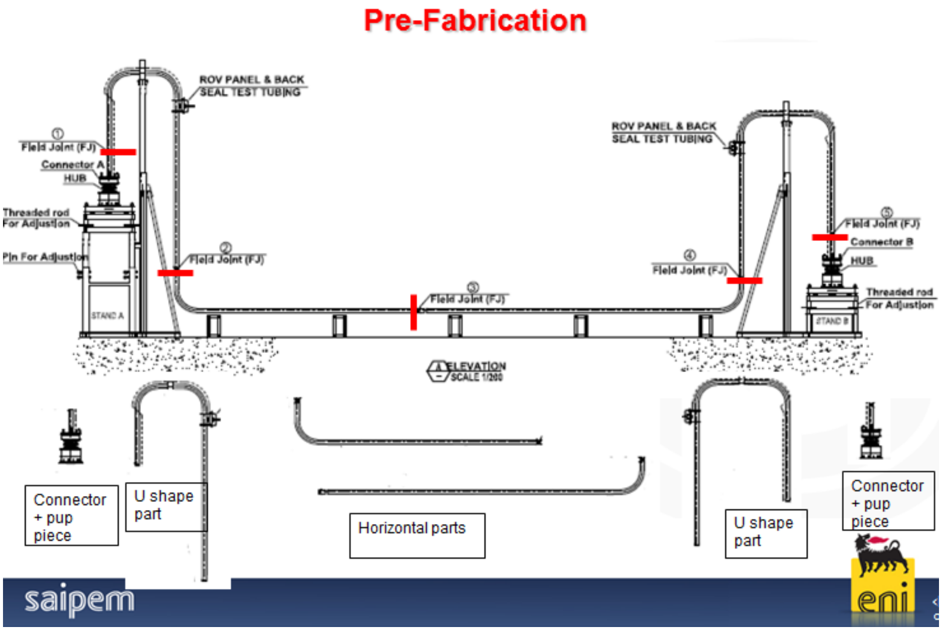


Figure 24. Pre fabrication of a Jumper

After the subsea hardware is installed, the distances between the components to be connected are measured or calculated. Then the connecting jumper is fabricated to the actual subsea metrology for the corresponding hub on each component. Pipes are fabricated to the desired length and provided with coupling hubs on the ends for the connection between the two components. Once the jumper has been fabricated, it is transported to the offshore location for the deployment of subsea equipment. The jumper will be lowered to the seabed, locked onto the respective mating hubs, tested, and then commissioned. If the measurements have not been precisely made or the components moved from their originally planned locations, new jumpers may need to be fabricated.

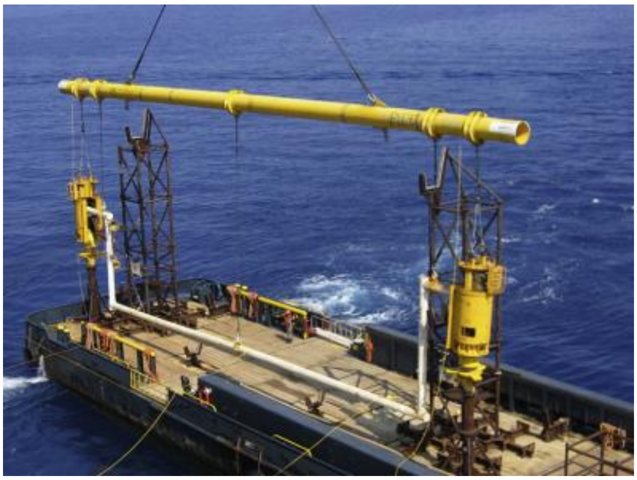


Figure 25. Shipping of a vertical jumper

The distance and the orientation between the subsea components must be known in advance before the fabrication of flowline jumpers because the lengths will be critical. Also, a small change in the jumper configuration should be considered when the jumper is lowered below the water surface and the dead load of jumper changes due to the buoyancy: otherwise, the jumper's dimensions may change and the jumper installation may fail. After the installation, if one of the components needs to be retrieved or moved, it is a time-consuming task to disconnect the flowline jumper from the component.
Figure 22 shows a transportation/shipping stand with a rigid jumper on a barge. The transportation/Shipping stands are designed to comply with:

- The stand should support the jumper in the installed configuration at the fabrication site or while en route to the installation site.
- The stand should not limit connector operation and access.
- It should have access ladders and work platforms if required
- It should allow for welding down for transport of a jumper offshore
- It should be designed to accommodate shipping of different jumper sizes.
- It should use a guide funnel to facilitate installation of a jumper.

Spreader Bar for Vertical Jumpers **Spreader Frame for Horizontal Jumpers**

Figure 26. Lowering of the Vertical & Horizontal Jumpers

2.3.2 Stroking

The stroking is the operation that consists in the connection of the jumper ends with the connector structures. Indeed the mechanical collet in the horizontal configuration of Jumpers at the extremity implies the need for a compression of the extremities. This load will be considered in the model considered by an imposed displacement (in compression) at the extremities with a stroking length value.

2.3.3 Offshore Hydrotest & Leak Test

The Pre-Commissioning operations are to test the integrity of the lines and the jumper installed. Consequently higher pressure (1.25 times the operating pressure for the Hydrotest) with water content flowing is applied to the lines. Pressure tightness can be tested by shutting off the supply valve and observing whether there is a pressure loss. Possible default in installation, material failure or leak can be detected with those tests. The design of the jumper will consider the cases of pre-commissioning activities considering the extra pressures in order to evaluate the stress induced in the Jumper and Spool structures. The line expansions of the Hydrotest and Leak test are applied on the jumper extremities.

2.3.4 Design and Operating

The Operating conditions are defined in accordance with the well content exploitation. The Maximum Allowable Operating Pressure (MAOP) is a design basis data. It corresponds to how much pressure of the well may safely hold in normal operation. Design pressure is the maximum pressure a pressurised item can be exposed to. Those pressures should constitute loading test of the structure and will be part of the conditions studied by the ABAQUS and AUTOPIPE models. The line expansions associated with the design and operating conditions should also be distinguished as they will impose displacements to the jumper extremities.

2.3.5 Shut Down

In case no content is flowed into the Jumper, the internal pressure will be very low compared to the external hydrostatic pressure. The Shut Down case considers that the internal pressure is zero. The complete shutdown of the well would entail such a situation. Comparing the stress range between the operating and the shutdown case is the basis for the evaluation of the fatigue life of the Jumper.

2.3.6 Retrieval

Finally the retrieval of the jumper, which corresponds to an inverse stroking (in the case of horizontal Jumpers), is to be tested. An extra imposed displacement at the extremities should be applied in the AUTOPIPE and ABAQUS models. This load case is not usually studied but it can be asked if the client company aims at retrieving the jumpers.

2.4 DESIGN GUIDELINES

Jumper length is defined according to the layout configuration. The target boxes of each end extremities allow the engineer to define Near-Near (NN), Far-Far (FF), Nominal (N), Near Near (NN), Worst Angle and Far Far Worst Angle (FFWA) configurations. The lengths of each configuration will be different and the angle with the existing lines will also differ.

The Attachment E presents the jumper layouts used for the Bonga North West project conducted by Saipem in 2012.

Due to allowable constraints, jumper height must change between configurations (NN – FF). A sensitivity can be performed to determine the cutoff for height vs hub-hub length to remain within allowable design envelopes. Indeed a longer jumper would not be able to stay within the limits if the loops heights are too important. However shorter jumpers can withstand higher loops.

Buoyancies can also be added along the length of the Jumper. Usual places for settling buoyancy modules are the two vertical internal straights as well as the longer horizontal straight section. The buoyancy is modeled by concentrated upward vertical force with common values around 6000 kN. The buoyancies limit the deflection of the Jumper thus limiting the stress.

Eventually the reaction loads at the extremities should be checked under the allowable loads for the connector’s hubs and adjacent structures. The shear force, the vertical force, the bending moment and the torsion must be into the allowable limits.

3. DESIGN REQUIREMENTS FOR SPOOLS AND JUMPERS

3.1 INTERNATIONAL PIPING STANDARDS

The subsea environment induces challenges for structure design: inaccessibility of the seabed, dynamic positioning and difficult accuracy of installation, high pressure and thermal loads, corrosion and scale, erosion and settlement of the structures at the seabed, water currents, flow assurance concern, dramatic costs of repair. Consequently the design of subsea structures is very demanding in terms of quality and respect of norms. That’s the reason why the industry follows the design rules of international codes.
A pipeline clearly has to be strong enough to withstand all the loads that will be applied to it. It will be loaded by internal pressure from the fluid it carries, by external pressure from the sea, and by stresses induced by

temperature changes. Sometimes it will be loaded by external impacts from anchors and fishing gear.

Two main code give recommendations for the design of pipes and subsea pipelines: the American Society of Mechanical Engineer (ASME) section B31, and the Det Norske Veritas (DNV).

3.1.1 ASME B31 Standards of Pressure Piping

ASME B31 covers Power Piping, Fuel Gas Piping, Process Piping, Pipeline Transportation Systems for Liquid Hydrocarbons and Other Liquids, Refrigeration Piping and Heat Transfer Components and Building Services Piping. ASME B31 was earlier known as ANSI B31.

3.1.1.1 History of ASME code

On March 20, 1905, a disastrous boiler explosion occurred in a shoe factory in Brockton, Massachusetts, killing 58 persons, injuring 117 others and causing a quarter of a million dollars in property damage.

Figure 27. US Shoe factory before and after the explosion

This catastrophic accident made the people of Massachusetts aware of the necessity of legislating rules and regulations for the construction of steam boilers in order to ensure their maximum safety. The state enacted the first legal code of rules for the construction of steam boilers in 1907. In 1908, the state of Ohio passed similar legislation, the Ohio board of boiler Rules adopting, with a few changes, the rules of the Massachusetts Board. Therefore, other states and cities in which explosions had taken place began to realize that accidents could be prevented by proper design, construction and inspection of boilers and pressure vessels and began to formulate rules and regulations for this purpose. As regulations differed from state to state and often conflicted with one another, manufacturers began to find it difficult to construct vessels for use in one state that would be accepted in another. Because of this lack of uniformity, both manufactures and users made an appeal in 1911 to Council of the American Society of Mechanical Engineers to correct the situation. The Council answered the appeal by appointing a committee ‘to formulate standard specifications for construction of steam boilers. The first committee consisted of seven members, all experts in their respective fields: one boiler insurance engineer, one material manufacturer, two boiler manufacturers, two professors of engineering and one consulting engineer. The committee was assisted by an advisory committee of 18 engineers representing various phases of design, construction, installation and operation of boilers. Following a thorough study of the Massachusetts and Ohio rules and other useful data, the committee made its preliminary report in 1913 and sent 2000 copies of it to professors of mechanical engineering, engineering departments of boiler insurance companies, chief inspectors of boiler inspection departments of states and cities, manufacturers of steam boilers, editors of engineering journals and others interested in the construction and operation of steam boilers, with a request for suggestions of changes or additions to the proposed regulations. After three years of countless meetings and public hearings, a final draft of the first ASME Rules for Construction of Stationary Boilers and for allowable Working Pressure, known as the 1914 edition, was adopted in spring of 1915.

3.1.1.1 Outline of Section VIII ASME B31.8

Section VIII of ASME B31.Ref[9] is dedicated to offshore gas transmission piping. This chapter is divided into:

-A801 General

-A802 Scope and intent

-A803 Offshore gas transmission terms and definitions

-A811 Qualification of materials and equipment

-A814 Material specifications

-A817 Conditions for the reuse and requalification of pipe

-A820 Welding offshore pipelines

-A823 Qualification of procedures and welders

-A825 Stress relieving

-A826 Inspection of welds

-A830 Piping system components and fabrication details

-A832 Expansion and flexibility

-A834 Support and anchorage for exposed piping

-A835 Anchorage for buried piping

-A840 Design, Installation, and testing

-A841 Design considerations

-A842 Strength considerations

-A843 Compressor stations

-A844 On-bottom stability

-A847 Testing

-A850 Operating and maintenance procedures affecting the safety of gas transmission facility

-A851 Pipeline maintenance

-A861 External corrosion control

-A864 Internal corrosion control

The stress equations and design factors are given in the part A842.Strength considerations. Both the steps of pipeline installation and pipeline operations should be studied with specific considerations.

During all phases of pipeline system installation (i.e. handling, laying, trenching and testing) the system should respect the minimum safety requirements against the following possible modes of failure:

Design against yielding:

When in operation, pressure and thermal forces act on the pipe, which tend to expand the pipeline both axially and longitudinally. These are due to internal pressure and temperature difference between the pipe and surrounding fluid.

3.1.1.1.1 Hoop Stress

Internal pressure from the contained fluid is the most important loading a pipeline has to carry. It is easy to forget how large the forces generated by pressure are. Figure28 shows a typical large diameter gas pipeline of 30in (0.762m) carrying an internal pressure of 15MPa. Half the pipe and half the contents are redrawn in Figure 29.b. pressing downwards on a 1 m length of this system is the pressure of the gas multiplied by the area over which it acts, a rectangle 0.75 m broad and 1m long. Pulling upwards on the same 1 m length is the tension in the pipe walls. There are no other vertical forces in a straight section of pipe. Since the system is in equilibrium, the tension in the pipe walls must be :

$$\Delta P * (W * L) = Force$$

Which gives :

$$15MPa * 0{,}75m^2 = 11{,}25MN$$

This value is 1100 tons, a substantial force, more than the take-off weight of three 747 aircrafts.

The hoop stress generated by internal pressure is statically determined, so that no significant stress redistribution can occur. If the hoop stress is too large, the pipeline can yield circumferentially and lead to rupture.

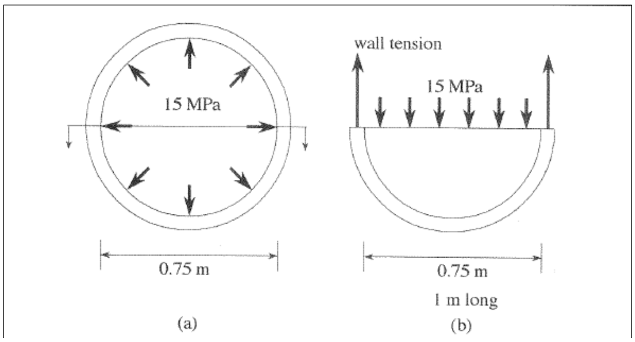


Figure 28. Forces in pressurized pipeline

A pipeline is a pressure vessel in the form of a cylinder, and, for this reason, some of the most detailed information available is obtained in the literature for pressure vessel design. Pipes with D/t greater than 30 are referred to as thin-wall pipes, and that with D/t less than 30 are called thick-wall pipes

-The tensile hoop stress due to the difference between internal and external pressures should not exceed the value given below.

Note : sign convention is such that tension is positive and compression negative.

$$Sh \leq F1 * S * T \qquad (1)$$

$$Sh = \frac{(Pi - Pe) * D}{2 * t} \qquad (2)$$

$$Sh = \frac{(Pi - Pe) * (D - t)}{2 * t} \qquad (3)$$

Eq. (2) is used for D/t greater than or equal to 30; and Eq. (3) is used for D/t less than 30.

$D = nominal\ outside\ diameter\ of\ pipe, in.\ (mm)$
$F1 = hoop\ stress\ design\ factor\ from\ Table\ A842.2.2.2 - 1\ (Section\ 1.2.1.2.4)$
$Pe = external\ pressure, psi\ (kPa)$
$Pi = internal\ pressure, psi\ (kPa)$
$S = specified\ minimum\ yield\ strength, psi\ (MPa)$
$Sh = hoop\ stress, psi\ (MPa)$
$T = temperature\ derating\ factor\ from\ Table\ 841.1.8 - 1\ (Section\ 1.2.1.2.4)$
$t = nominal\ wall\ thickness, in.\ (mm)$

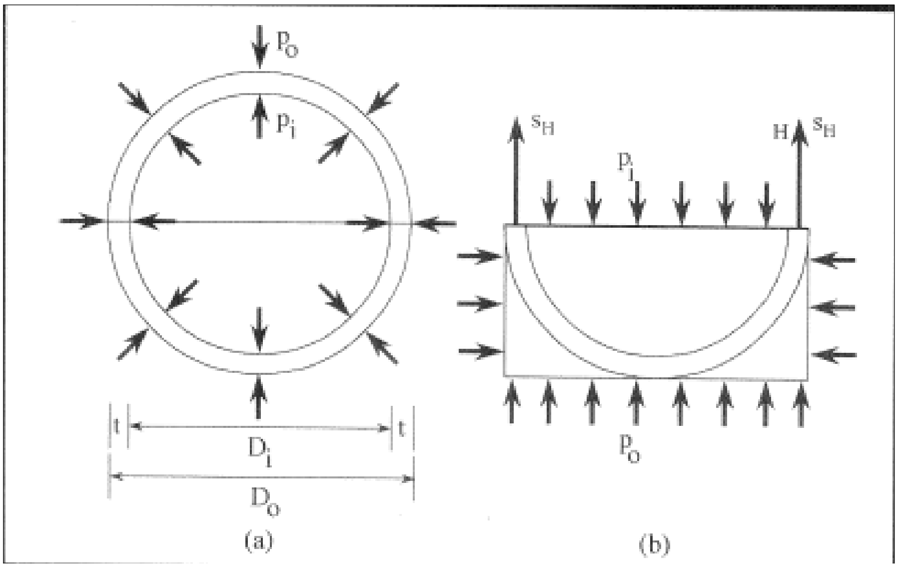


Figure 29. Circumferential stress in a Pipeline pressurized Internally and Externally

The design factor of the stress check equations are given in the Table A842.2.2-1 of the ASME B31.8 code.

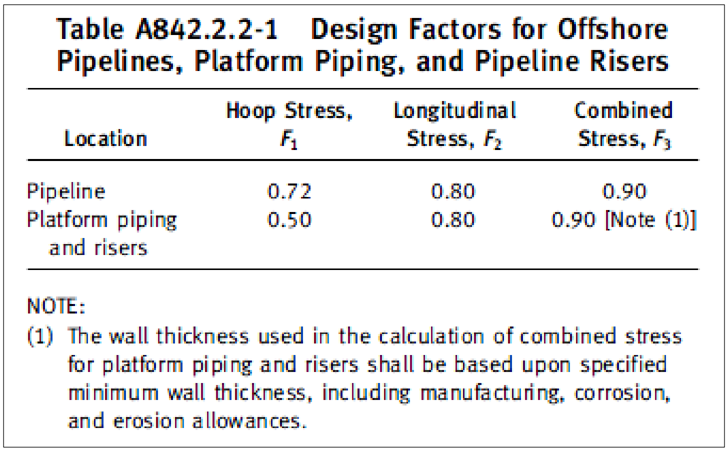


Table A842.2.2-1 Design Factors for Offshore Pipelines, Platform Piping, and Pipeline Risers

Location	Hoop Stress, F_1	Longitudinal Stress, F_2	Combined Stress, F_3
Pipeline	0.72	0.80	0.90
Platform piping and risers	0.50	0.80	0.90 [Note (1)]

NOTE:
(1) The wall thickness used in the calculation of combined stress for platform piping and risers shall be based upon specified minimum wall thickness, including manufacturing, corrosion, and erosion allowances.

Table 7. Design factor for Hoop, Longitudinal and Combined Stresses

The high temperature conditions have influence on the strength of the pipe material. Consequently Temperature Derating Factor is used to correct the equations of the codes.

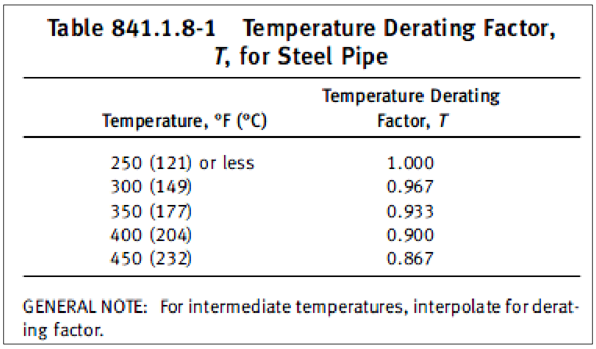


Table 841.1.8-1 Temperature Derating Factor, *T*, for Steel Pipe

Temperature, °F (°C)	Temperature Derating Factor, *T*
250 (121) or less	1.000
300 (149)	0.967
350 (177)	0.933
400 (204)	0.900
450 (232)	0.867

GENERAL NOTE: For intermediate temperatures, interpolate for derating factor.

Table 8. Temperature Derating Factor

3.1.1.1.2 Longitudinal Stress

A pipeline in operation carries longitudinal stress as well as hoop stress. Longitudinal stresses arise from two effects.

First the Poisson effect: a bar loaded in tension extends in the tension direction and contracts transversely. If transverse contraction is prevented, a transverse tensile stress is set up. The analysis of hoop stress shows that internal pressure induces circumferential tensile stress. If there were only circumferential stress and no longitudinal stress, the pipe would extend circumferentially (increase of diameter) but would contract longitudinally (shorter pipe). If friction against the seabed or attachment to fixed objects such as platforms prevents longitudinal contraction, a longitudinal tensile stress occurs.

The second effect is temperature. If temperature of a pipeline increases and if the pipeline is free to expand in all direction, it expands both circumferentially and axially. Circumferential expansion is usually completely unconstrained, but longitudinal expansion is constrained by seabed friction and structures tied to the pipeline. It follows that if expansion is prevented, a longitudinal compressive stress will be induced in the pipe.

Expansion stresses can be very large. the stress required to suppress uniaxial expansion completly under a temperature difference θ is $E\alpha\theta$ where E is the elastic modulus and α is the linear thermal expansion coefficient. For steel, $E\alpha$ is 2.4 N/mm^2 degC, so that a temperature increase of 100° in a constrained situation induces a longitudinal stress of 240 MPa, which can be an important fraction of the yield strength.

-The longitudinal stress shall not exceed the values found from:

$$|Sl| \leq F2 * S$$

With

$$A = cross - sectional\ area\ of\ pipe\ material, in^2 (mm^2)$$
$$Fa = axial\ force, lb\ (N)$$
$$F2 = longitudinal\ stress\ design\ factor\ from\ Table\ A842.2.2.2 - 1\ (Section\ 1.2.1.2.4)$$
$$Mi = in - plane\ banding\ moment, in - lb\ (N.m)$$
$$Mo = out - plane\ bending\ moment, in - lb\ (N.m)$$
$$S = specified\ minimum\ yield\ strength, psi\ (MPa)$$
$$Sl = maximum\ longitudinal\ stress, psi\ (positive\ tensile\ or\ negative\ compressive)(MPa)$$
$$= Sa + Sb\ or\ Sa - Sb\ whichever\ result\ in\ the\ larger\ longitudinal\ stress\ value$$
$$Sa = axial\ stress, psi\ (positive\ tensile\ or\ negative\ compressive)(MPa) = \frac{Fa}{A}$$
$$Sb = resultant\ bending\ stress, psi\ (MPa) = \frac{[(iiMi)^2 + (ioMo)^2]^{\frac{1}{2}}}{Z}$$
$$ii = in - plane\ stress\ intensification\ factor$$
$$io = out - plane\ stress\ intensification\ factor$$
$$Z = section\ modulus\ of\ pipe, in^3 (cm^3)$$

3.1.1.1.3 Combined Stress

-The combined stress should not exceed the value given by the maximum shear stress equation (Tresca combined stress):

$$2 * \left[\left(\frac{Sl - Sh}{2}\right)^2 + St^2\right]^{\frac{1}{2}} \leq F3 * S$$

With

$$A = cross - sectional\ area\ of\ pipe\ material, in^2 (mm^2)$$
$$Fa = axial\ force, lb\ (N)$$
$$F3 = combined\ stress\ design\ factor\ from\ Table\ A842.2.2.2 - 1$$
$$Mi = in - plane\ bending\ moment, in. -lb\ (N.m)$$
$$Mo = out - plane\ bending\ moment, in. -lb\ (N.m)$$
$$Mt = torsional\ moment, in. -lb\ (N.m)$$
$$S = specified\ yield\ strength, psi\ (MPa)$$
$$Sl = maximum\ longitudinal\ stress, psi\ (positive\ tensile\ or\ negative\ compressive)(MPa)$$
$$= Sa + Sb\ or\ Sa - Sb, whichever\ results\ in\ the\ larger\ combined\ stress\ value$$
$$Sa = axial\ stress, psi\ (positive\ tensile\ or\ negative\ compressive)(MPa) = \frac{Fa}{A}$$
$$Sb = resultant\ bending\ stress, psi(MPa) = \frac{[(ii * Mi)^2 + (io * Mo)^2]^{\frac{1}{2}}}{Z}$$
$$Sh = hoop\ stress, psi\ (MPa)$$

$$St = torsional\ stress, psi(MPa) = \frac{Mt}{2 * Z}$$
$$ii = in - plane\ stress\ intensification\ factor$$
$$io = out - plane\ stress\ intensification\ factor$$
$$Z = section\ modulus\ of\ pipe, in^3 (cm^3)$$

Alternatively, the Maximum Distortion Energy (Von Mises combined stress) may be used for limiting combined stress value:

$$\boxed{(Sh^2 - Sl * Sh + Sl^2 + 3 * St^2)^{\frac{1}{2}} \leq F3 * S}$$

As seen previously, the ASME B31.8 is based on allowable-stress design using the yield strength of the material. This approach is always conservative. Another method of design would be Limit-state design which consists on evaluating the critical loads that lead to failure and design the structures so that in operating mode it is always far from the failure condition. This approach would be less conservative since the structure would be allowed to reach yield point.

Design against buckling:

Theoretically, buckling is caused by a bifurcation in the solution to the equations of static equilibrium. At a certain stage under an increasing load, further load is able to be sustained in one of two states of equilibrium: an unstable un-deformed state or a stable laterally-deformed state.

In practice, buckling is characterized by a sudden failure of a structural member subjected to high compressive stress, where the actual compressive stress at the point of failure is less than the ultimate compressive stresses that the material is capable of withstanding. Mathematical analysis of buckling often makes use of an axial load eccentricity that introduces a secondary bending moment, which is not a part of the primary applied forces to which the member is subjected. As an applied load is increased on a member, such as column, it will ultimately become large enough to cause the member to become unstable and is said to have buckled. Further load will cause significant and somewhat unpredictable deformations, possibly leading to complete loss of the member's load-carrying capacity.
Moreover the pipelines are subjected to compression due to expansions, the force applied can trigger buckling of the line. Consequently avoidance of buckling of the pipeline shall be considered in the design.

Figure 30. Pipeline global buckling

Design against Fatigue:

Stress fluctuations of sufficient magnitude and frequency which are susceptible to induce significant fatigue should be considered in design. Loading that may affect fatigue include:

a) Startup / Shut Down (Pressure and Temperature Cycles)

The change in temperature and pressure conditions inside the pipeline induces fatigue loads. The expansions cycles due to temperature are causing such actions.

b) Waves actions

Wave loads being repetitive on the pipe, they can also trigger shorter fatigue life.

c) Vibration Induced by Vortex (VIV)

In fluid dynamics, vortex shedding is an oscillating flow that takes place when a fluid such as air or water flows past a cylindrical body. In this flow, vortices are created at the back of the body and detach periodically from either side of the body. If the cylindrical structure is not mounted rigidly and the frequency of vortex shedding matches the resonance frequency of the structure, the structure can begin to resonate, vibrating with harmonic oscillations driven by the energy of the flow. Vortex shedding was one of the causes proposed for the failure of the original Tacoma Narrows Bridge in 1940, but was rejected because the frequency of the vortex shedding did not match that of the bridge. The bridge actually failed by aeroelastic flutter.

Pipelines spans should be designed so that Vortex Induced resonant Vibrations (VIV) are prevented. Nowadays the standard DNV code is a reference in term of fatigue life calculation. Pipeline Strakes are commonly used on Jumpers and Spools to introduce turbulence of the flow so that the load is less variable and resonant load frequencies have negligible amplitudes


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Figure 31. Buoys and Strakes for Jumpers

Design against Fracture:

Materials used for pipelines transporting gas or gas-liquid mixtures under high pressure should have reasonably high resistance to propagating fractures at the design conditions.

Design of Clamps and Supports:

Clamps and Supports shall be designed such that a smooth transfer of loads is made from the pipeline to the supported structure without highly focalized stress concentrations. The loads applied by the structure on each connector end will be checked and compared to the allowable loads of the connectors. Connectors and flanges shall have a level of safety against failure by yielding and failure by fatigue that is comparable to that of the attached pipeline.

Design of structural pipeline:

Where pipelines are installed in location subject to impact from marine traffic, protective devices shall be installed. Additional considerations include design storm currents, seabed movements, soil liquefaction, increased potential corrosion, thermal expansions and contraction.

3.1.1.2 Loads considered for Spools and Jumpers Design

A number of physical parameters, henceforth referred to as design conditions, govern design of the offshore pipeline systems so that it meets installation, operation, and other post installation requirements. The loads and factors that should be taken into account are:

-pressure load: the differences of pressures whether it be in operations or in shut down configurations, will create important stresses.

-***weight***: the effect of pipe assembly weights (in air and submerged) as well as the variability due to weight coating tolerances and water absorption should be considered.

-***thermal expansions***: expansions of the lines as well as the expansion of the jumper itself due to thermal loads shall be taken into account for the design of the structures. Those expansions are modelled by imposed displacements at the extremities of the structure.

-***linear and angular tolerances***: metrology and installation tolerances shall be tested in advance to the installation procedure in order to ensure the conservatism of the solutions chosen whatever the configuration is at the time of the installation.

-***buoyancy***: the action of buoyancy modules shall be modeled as they are used to relieve the jumper/spool from the bending moments due to self-weight.

-***wave actions***: current velocity with the drag and lift effect should be applied on the structure. Additionally studies of the Vortex Induced Vibrations and fatigue life have to be conducted.

-***marine soil***: if contact happens the model should be accordingly configured with the friction coefficients of the soil.

-***support settlement***: both the initial settlement and the long-term settlement of the end structures will have influence on the jumper behavior.

3.1.2 DNV, Det Norske Veritas

3.1.2.1 History of DNV code

DNV was organized as a foundation, with the objective of "Safeguarding life, property, and the environment". The organization's history goes back to 1864, when the foundation was established in Norway to inspect and evaluate the technical condition of Norwegian merchant vessels. The foundation is oraganized into 3 corporations: DNV Maritime and Oil & Gas, DNV KEMA Energy & Sustainability, DNV Business Assurance.

3.1.2.2 Outline of Pressure Piping

The design of Jumpers with the prime design code DNV OS-F101 is based on Load and Resistance Factor Design (LRFD) which ensured a satisfactory level of safety when the design load effect does not exceed the design resistance.

The jumper bends are also required to satisfy the requirement for combined loading local buckling. In addition, all the bends shall be checked using Allowable Stress Design (ASD) in accordance with DNV OS-F-101, Section 5 F200.

The fundamental principle of the Load and Resistance Factor Design (LRFD) format is that design load effects, Lsd, do not exceed design resistances, Rrd, for any of the considered failure modes in any load scenario:

$$f(\left(\frac{Lsd}{Rrd}\middle|i\right)) \leq 1$$

Where

$$Lsd = the\ design\ load$$

$$Rrd = design\ resistance$$

$$i = the\ different\ loading\ types$$

The design load effect can generally be expressed as :

$$Lsd = L_F * \gamma_F * \gamma_C + L_E * \gamma_E + L_I * \gamma_F * \gamma_C + L_A * \gamma_A * \gamma_C$$

Where Lf, Le, Li and La are the functional, environmental, interference and accidental loads. The function load corresponds to the pressure and temperature conditions while the environmental loads are considering the wave actions. The interference loads are modelling the loads induced by dropping objects on the pipes or fishing tools. In specific forms, this corresponds to :

$$M_{sd} = M_F * \gamma_F * \gamma_C + M_E * \gamma_E + M_I * \gamma_F * \gamma_C + M_A * \gamma_A * \gamma_C$$

$$\varepsilon_{sd} = \varepsilon_F * \gamma_F * \gamma_C + \epsilon_E * \gamma_E + \varepsilon_I * \gamma_F * \gamma_C + \epsilon_A * \gamma_A * \gamma_C$$

$$S_{sd} = S_F * \gamma_F * \gamma_C + S_E * \gamma_E + S_I * \gamma_F * \gamma_C + S_A * \gamma_A * \gamma_C$$

Where Msd, Esd, Ssd are the design moment, design strain and design effective axial force. The coefficients ɣF, ɣE, ɣA are the functional, environemental and accidental load factors and ɣC the load condition factor. They are given in the following table.

Limit State / Load Combination		Functional Loads	Environmental Loads	Interference Loads	Accidental Loads
		γ_F	γ_E	γ_F	γ_A
ULS	a	1.2	0.7	N/A	N/A
	b	1.1	1.3	1.1	N/A
FLS		1.0	1.0	1.0	N/A
ALS		1.0	1.0	1.0	1.0

Table 9. Load Effect factor and Load Combination

Condition	γ_c
Pipeline resting on uneven seabed	1.07
Continuous stiff supported	0.82
System pressure test	0.93
Otherwise	1.00

Table 10. Condition Load Effect Factors

The relevant limit states (failures modes) are: Serviceability Limit State Category (SLS), Ultimate Limit State Category (ULS), Fatigue Limit States (FLS) and Accidental Limit State (ALS).

The design resistance is generally expressed as :

$$R_{RD} = \frac{R_c(f_c, t_c)}{\gamma_m * \gamma_{sc}}$$

Where

$$Rc = characteristic\ resistance$$

$$f_c = characteristic\ material\ strength, refer\ following\ material\ explanation$$

$$t_c = characteristic\ wall\ thickness$$

$$\gamma_m = material\ resistance\ factors$$

$$\gamma_{sc} = safety\ class\ resistance\ factors$$

Two different characterisations of the wall thickness tc are used : t1 and t2. Thickness t1 is used where failure is likely to occur in connection with a low capacity while thickness t2 is used when failure is likely to occur with an extreme load effect.

The material resistance factor, γ_m, is dependent on the limit state category and is defined in the following table :

Limit State Category	SLS / ULS / ALS	FLS
γ_m	1.15	1.00

Table 11. Material Resistance Factor

The safety class resistance factor, γ_{sc}, is dependent on the safety class considered and is defined in the following table :

Safety Class	γ_{SC}
Low	1.04
Medium	1.14
High	1.26

Table 12. Safety Class Resistance Factor

Characteristic material properties shall be used in the resistance calculations. The yield stress and tensile strength in the limit state formulations shall be based on the engineering stress-strain curve. The characteristic material strength values to be used are defined as below.

$$f_y = \left(SMYS - f_{y,temp}\right) * \alpha_u$$

$$f_u = \left(SMYS - f_{u,temp}\right) * \alpha_u$$

Where

$f_{y,temp}, f_{u,temp}$ the derating factors due to temperature of the yield, and tensile strength respectively.
α_u the material strength factor and is to be taken as 0.96 as no supplementary requirement applies.

In line with ENG-20-SAMG-AEMG-TQR-000011, DNV Local Buckling – Pipe Dimension Limits, Ref.[42], for load controlled conditions, pipe members subjected to the combined loading and internal overpressure shall be designed to satisfy the following requirements

$$\left(\frac{\gamma_m * \gamma_{sc} * |M_{sd}|}{\alpha_c * M_p(t2)} + \left(\frac{\gamma_m * \gamma_{sc} * S_{sd}(pi)}{\alpha_c * S_{p(t2)}}\right)^2\right)^2 + \left(\alpha_p * \frac{pi - pe}{\alpha_c * pb(t2)}\right)^2 \leq 1$$

Where

$$M_{sd} = design\ moment$$
$$S_{sd} = design\ effective\ axial\ force$$
$$pi = internal\ pressure$$
$$pe = external\ pressure$$
$$pb = burst\ pressure$$

With :

$$pb = 2 * \frac{t}{D - t} * fcb * \frac{2}{\sqrt{3}}$$

$$fcb = Min[f_y; \frac{f_u}{1.15}]$$

$$Sp, Mp = platic\ capacities\ for\ a\ pipe$$

With :

$$Sp(t) = f_y * \pi * (D - t) * t$$

$$Mp(t) = f_y * (D - t)^2 * t$$

And

$$\alpha_c = flow\ stress\ parameter$$

$$\alpha_p = account\ for\ the\ effect\ of\ \frac{D}{t} ratio$$

Calculated by :

$$\alpha_c = (1 - \beta) + \beta * \frac{f_u}{f_y}$$

$$\beta = \begin{cases} 0.5\ if\ D/t2 < \frac{2}{3} \\ \left(\frac{60 - \frac{D}{t2}}{90}\right)\ if\ 15 \leq \frac{D}{t2} \leq 60 \\ 0\ if\ \frac{D}{t2} > 60 \end{cases}$$

And :

$$\alpha_p = \begin{cases} 1 - \beta \; if \; \dfrac{pi - pe}{pb} < \dfrac{2}{3} \\ 1 - 3 * \beta \left(1 - \dfrac{pi - pe}{pb}\right) \; if \; \dfrac{pi - pe}{pb} \geq 2/3 \end{cases}$$

Under load controlled conditions, pipe members subjected to the combined loading and external overpressure shall be designed to satisfy the following requirements:

$$\boxed{\left(\frac{\gamma_m * \gamma_{sc} * \left|M_{sd}\right|}{\alpha_c * M_p(t2)} + \left(\frac{\gamma_m * \gamma_{sc} * S_{sd}(pi)}{\alpha_c * S_{p(t2)}}\right)^2\right)^2 + \left(\gamma_m * \gamma_{sc} * \frac{pe - pmin}{pc(t2)}\right)^2 \leq 1}$$

Where :

$$pmin = minimum\ internal\ pressure$$

$$pc = characteristic\ collapse\ pressure$$

$$\left(pc(t) - p_{el}(t)\right) * \left(p_c(t)^2 - p_p(t)^2\right) = pc(t) * p_{el}(t) * p_p(t) * f_0 * \frac{D}{t}$$

With :

$$p_{el}(t) = \frac{2 * E * \left(\frac{t}{D}\right)^3}{1 - v^2}$$

$$p_p(t) = f_y * \alpha_{fab} * 2 * \frac{t}{D}$$

$$f_o = \frac{Dmax - Dmin}{D}$$

Consequently knowing the maximum axial force and the maximum bending moment in the Jumpers & Spools will enable DNV checks.

4. THESIS ACTIVITY DESCRIPTION: JUMPERS & SPOOLS FEA DESIGN SPREADSHEETS

4.1 AUTOPIPE & ABAQUS FEA NUMERICAL MODELS

Finite Element Analysis are used to compute the values of the internal forces and moments in the complete jumper.
AUTOPIPE is a piping FEA software which includes characteristic functionalities for analysis in that field. Consequently the post-processing of the outputs data is performed automatically by the software to comply with the ASME code. However ABAQUS is a general FEA software thus manual post-processing of the outputs data will be necessary. AUTOPIPE will also require post-processing to comply with DNV standards. The following part will deal with the two FEA software used to model Jumpers and Spools. The input files and the theoretical concepts will be detailed.

4.1.1 AUTOPIPE

Bentley AutoPIPE v8 Plus Ref.[8]. is a PC-based pipe stress analysis program by Bentley Systems which uses a finite element method to calculate the piping response to self-weight, pipe contents and external loads for subsea applications, taking into account the piping stiffness. Boundary conditions are applied at the restrained nodes of the model.

All the models created have the following common features:

- The model consists of pipe elements for straight section and elbow elements for bends. AutoPIPE automatically calculate the flexibility and stress intensification factor based on ASME B31.8 piping code, for bends.
- The connectors are modelled as pipe elements with the effective submerged net weight and conservative stiffness.
- Buoyancy module is modelled as an uplift force with net buoyancy where as appropriate.
- The ends of the model are anchored with the imposed displacements to simulate the tolerance / misalignment and/or pipeline expansion as appropriate.
- The end cap effect is automatically computed by AutoPIPE.
- Environmental loading due to current is determined using AUTOPIPE and applied in the most onerous directions. The Morison equation $F = \frac{1}{2} * C_D * \rho * V^2$ is used to model such actions.
- Soil is modelled as contact elements with downward linear stiffness and lateral friction.

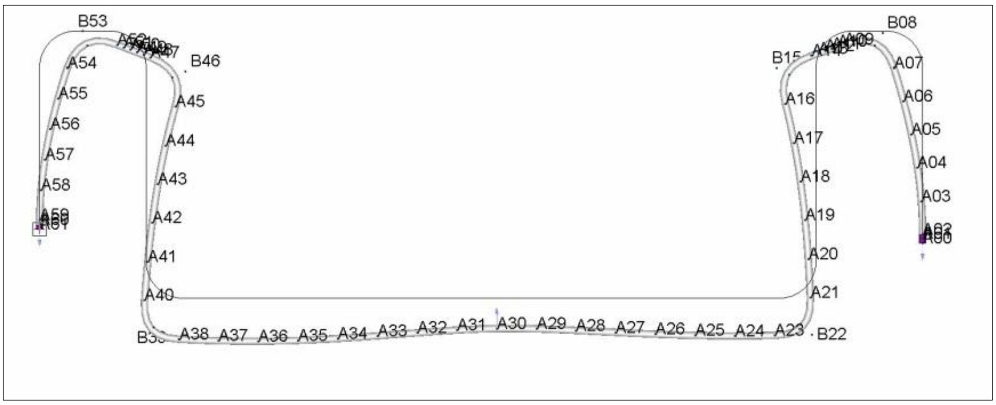


Figure 32. Autopipe view, Jumper under gravity load & middle buoyancy

The input file of AUTOPIPE are *.NTL file. Indeed it is possible to model structures on AUTOPIPE whether using the software module or redacting input files. The advantage of possible automatism favors the use of *.NTL files (See Attachment B for a typical NTL file)

The model geometry is created by the introduction of straight and bend segments. The aim of this study is to model both 2D Jumpers and 3D Spools. Each extremity of segment will represent a node in the analysis. For the bend, the curvature radius should be computed.

The connectors at the extremities of the Jumpers will be modeled by rigid elements. The Hub length and the pup piece length of each jumper being different, it is necessary to define and parameterize the size of those extremities.
All the jumpers shall be designed to accommodate the following tolerances and misalignments:

- Metrology tolerance
- Fabrication tolerance
- Expansions
- Settlement

Through those tolerances are not very probable to combine synchronously, testing all the combinations enable the piping engineer to evaluate the most conservative situation. Additionally the expansions and the settlements will be added to the imposed displacements.
The angular & linear tolerances due to metrology and fabrication are listed below.

- ➢ DX : Linear tolerance along (OX) + Expansion projected on (OX)
- ➢ DY : Linear tolerance along (OY) + Expansion projected on (OY)
- ➢ DZ : Linear tolerance along (OZ) + Settlement

- ➢ RX : Angular tolerance (pitch)
- ➢ RY : Angular tolerance (yaw)
- ➢ RZ : Rotation around (OZ) axis (roll)

The displacements matrix will be generated automatically by the spreadsheet according to the load case considered.

The deformed shape of the structure is highlighting the gravity, the wave load and all the displacements. Opening the models developed via the coding *.NTL, Autopipe enables the user to check that the structure is correctly designed and the loads are well applied.

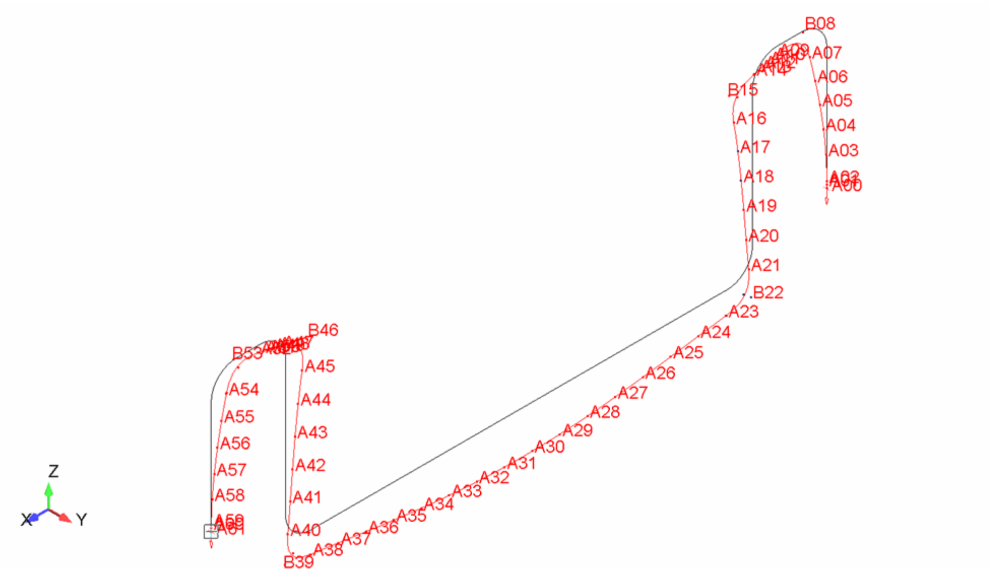


Figure 33. Autopipe view, Deformed shape jumper under gravity load

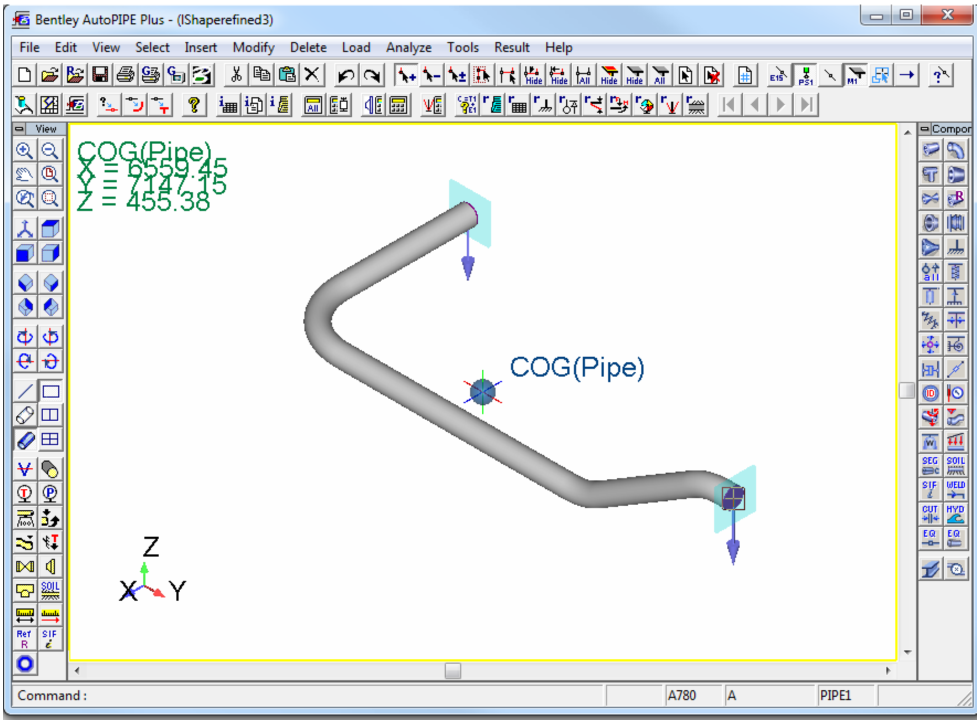
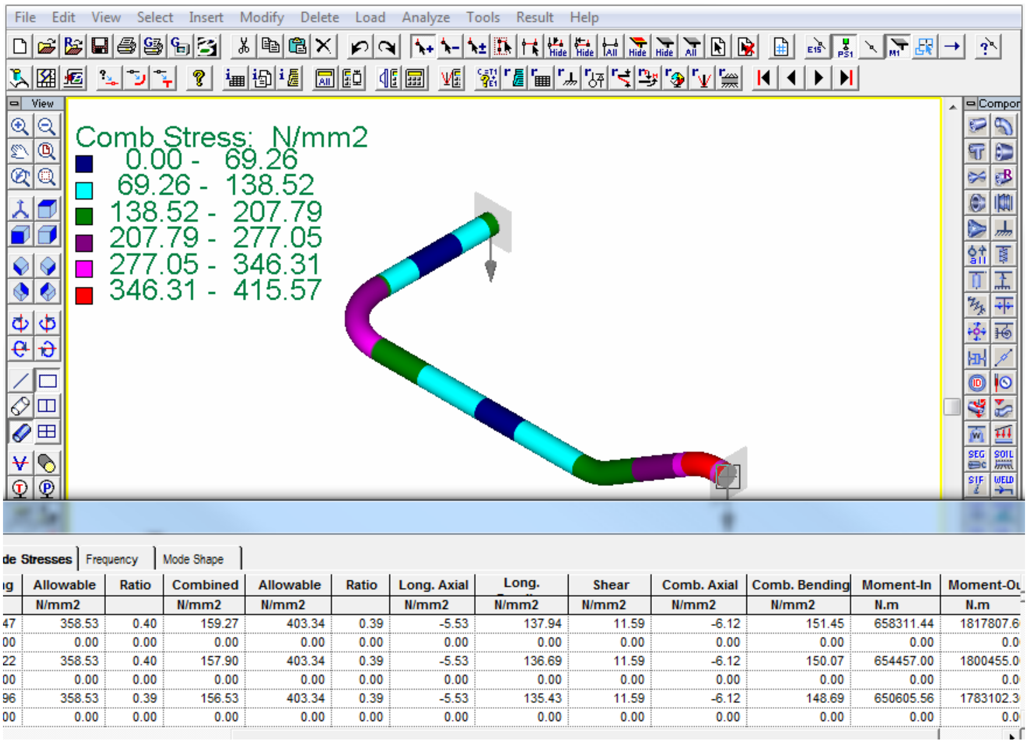


Figure 34. 3D Spool designed on Autopipe

Both vertical and horizontal Spools have been designed during the project. The Figure 34 shows a L shaped Spool that has been modelled with the fixed anchors at each extremities and the connector weight applied.

The software enables an easy post processing in compliance with ASME B31.8. Indeed it is possible to obtain directly the ratios of the hoop, longitudinal and combined stresses with the allowable stresses.



Comb Stress: N/mm2

■	0.00 - 69.26
■	69.26 - 138.52
■	138.52 - 207.79
■	207.79 - 277.05
■	277.05 - 346.31
■	346.31 - 415.57

ig	Allowable	Ratio	Combined	Allowable	Ratio	Long. Axial	Long.	Shear	Comb. Axial	Comb. Bending	Moment-In	Moment-Ou
	N/mm2		N/mm2	N/mm2		N/mm2	N/mm2	N/mm2	N/mm2	N/mm2	N.m	N.m
47	358.53	0.40	159.27	403.34	0.39	-5.53	137.94	11.59	-6.12	151.45	658311.44	1817807.6
00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0
22	358.53	0.40	157.90	403.34	0.39	-5.53	136.69	11.59	-6.12	150.07	654457.00	1800455.0
00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0
96	358.53	0.39	156.53	403.34	0.39	-5.53	135.43	11.59	-6.12	148.69	650605.56	1783102.3
00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0

Figure 35. ASME Stress checks are performed by Autopipe

4.1.2 ABAQUS

The 3D finite pipe element used in the established model is a two node twelve degree of freedom PIPE31H element. The element uses linear interpolation and therefore has a lumped mass distribution. The hybrid formulation makes the element well suited for case with slender structures and contact problems, such as a pipe lying on the seabed.

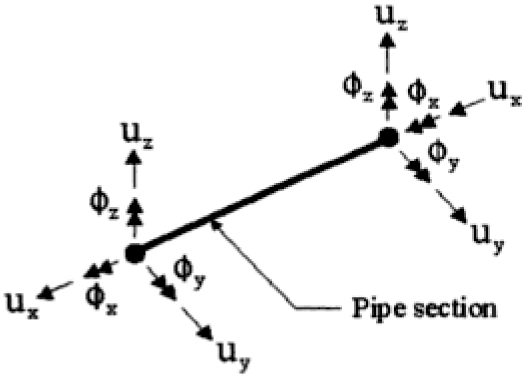


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Figure 36. Two nodes twelve degrees of freedom 3D pipe element

The hybrid elements are provided in Abaqus/Standard for use in cases where it is numerically difficult to compute the axial and shear forces in the beam by the usual finite element displacement method. The problem in such case is that slight differences in nodal positions can cause very large force in some part of the model, which, in turn cause large motions in other directions. The hybrid elements overcome this difficulty by using a more general formulation in which the axial and transverse shear forces in the elements are included, along, with the node displacements and rotations, as primary variables. Although this formulation makes these elements more calculation intensive, they generally converge much faster when the pipe rotations are large and are more efficient overall in such cases.

The PIPE31H element is available with a hollow thin-walled circular section and supports the possibility for the user to specify external and/or internal pressure. The element can also account for changes in the pipe section area due to high axial straining of the pipe.

Pipe elements (PIPE21, PIPE22, PIPE31, PIPE32 and their “hybrid” equivalents) allow for transverse shear deformation. (plane sections initially normal to beam’s axis do not always remain plane and normal to the beam axis. They can be used for thick as well as slender beams.

The element-based loads that will be applied on the model are :

- GRAV, gravity loading in a specified direction (magnitude is input as acceleration)
- PX, force per unit length in global X-axis (used for the Morison current actions along (OX))
- PY, force per unit length in global Y-axis (used for the Morison current actions along (OY))
- HPI, hydrostatic internal pressure (closed-end condition), varying linearly with the global Z-coordinate
- HPE, hydrostatic external pressure (closed-end condition), varying linearly with the global Z-coordinate

The element outputs are :

- S11 : Axial stress.
- S22 : Hoop stress.
- S12 : Shear stress caused by torsion.
- SF1 : Axial force.
- SF2 : Transverse shear force in the local 2-direction.
- SF3 : Transverse shear force in the local 1-direction.
- SM1 : Bending moment about the local 1-axis.

- SM2 : Bending moment about the local 2-axis.
- SM3 : Twisting moment about the beam axis.
- ESF1 : Effective axial force for beam subjected to pressure loading.

The effective axial force is calculated as :

$$ESF1 = SF1 + pe * Ae - pi * Ai$$

Where pe and pi are the external and internal pressures, respectively, and Ae and Ai are the external and internal pipe areas.

Starting from the output forces and moments, the axial stress, the bending moment, the longitudinal stress, the torsional stress and the combined stress will be computed.

- Axial Stress : $\boxed{Sa = \frac{Fendcap - ESF1}{A}}$

With: $Fendcap = End\ cap\ effect\ force = Ai * Pi - Ae * Pe\ [kN]$

$ESF1 = Effective\ Axial\ Force\ [kN]$

$A = Section\ Area = \frac{\pi}{4} * (D^2 - ID^2)\ [cm^2]$

- Bending Moment : $\boxed{Sb = \frac{\sqrt{((Io * SM2)^\wedge 2 + (Ii * SM3)^\wedge 2))}}{Z}}$

With: $SM2 = Moment\ Y - axis$

$SM3 = Moment\ Z - axis$

$Z = Section\ modulus = \left(\frac{\pi}{32}\right) * \frac{(D^4 - (ID_{nom})^4)}{D}\ [cm^3]$

$Io = out\ of\ plane\ Stress\ Intensification\ Factor = \ max\ (1, \frac{0.75}{h^{\frac{2}{3}}})$

$Ii = in\ plane\ Stress\ Intensification\ Factor = \ max\ (1, \frac{0.9}{h^{\frac{2}{3}}})$

$h = Flexibility\ factor = t.\frac{R1}{r2^2}$ with $R1 = 5D\ and\ r2 = \frac{D}{2}$

Longitudinal Stress : $\boxed{Sl = Max(Sa + Sb; Sa - Sb)}$

- Torsional Stress : $\boxed{St = \frac{SM1}{2 * Z}}$

With: $SM1 = Moment\ X - axis$

$Z = Section\ modulus = \left(\frac{\pi}{32}\right) * \frac{(D^4 - (ID_{nom})^4)}{D}\ [cm^3]$

- Combined Stress : $\boxed{Scb = MAX[2 * \sqrt{(}\left(\frac{Sh - (Sa - Sb)}{2}\right)^2 + St^2; 2 * \sqrt{(}\left(\frac{Sh - (Sa + Sb)}{2}\right)^2 + St^2]}$

With: $Sh = Hoop\ Stress$

The orientation of a beam cross-section is defined in Abaqus in terms of a local, right-handed ($\mathbf{t}$, $\mathbf{n}_1$, $\mathbf{n}_2$) axis system, where $\mathbf{t}$ is the tangent to the axis of the element, positive in the direction from the first to the second node of the element, and $\mathbf{n}_1$ and $\mathbf{n}_2$ are basis vectors that define the local 1- and 2-directions of the cross-section.

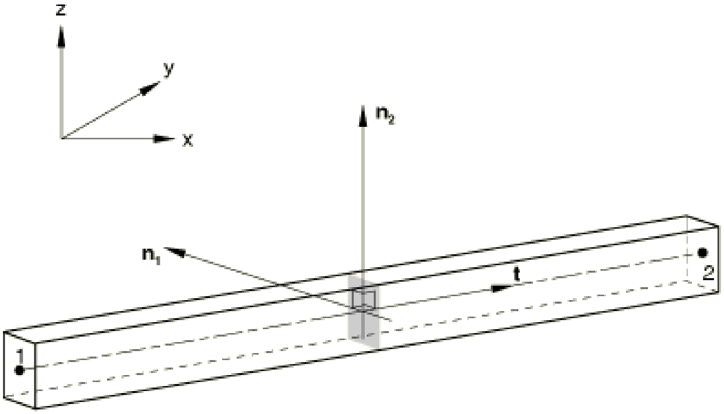


Figure 37. Beam orientation

In Abaqus, a series of points is entered and these points are linked by straight line segments, each of which is integrated numerically along the axis of the section so that the section can be used together with non-linear material behavior. An independent thickness is associated with each of the segments making up the arbitrary section.

Pipe cross section will be used in our model. The outside radius and wall thickness of the cross section are entered. The beam considered being in space, 8 integration points (trapezoidal rule) are used. The output points will be the points 1,3,5 and 7 in the figure above.

It would also be possible to use thick pipe sections if more accurate stress values inside the wall thickness would be required. Then three points would be created radially in the thickness.

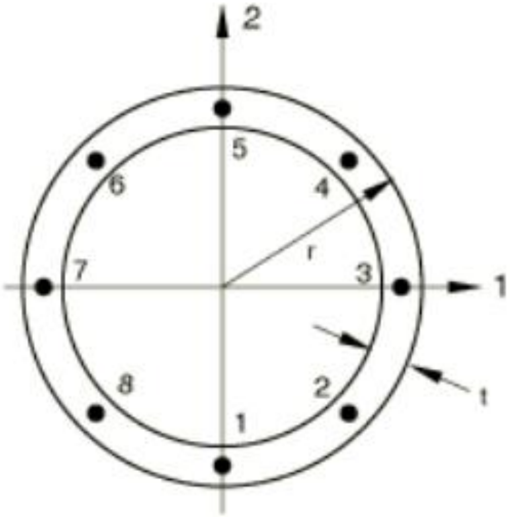


Figure 39. Default integration, beam in space, thin pipe section

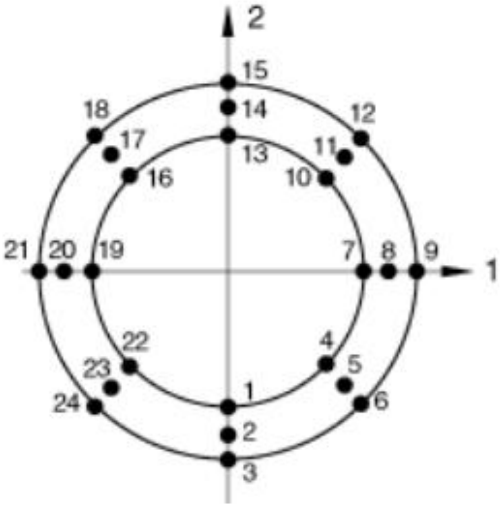


Figure 38. Default integration, beam in space, thick pipe section

Sensitivity analysis performed at Saipem have shown that element length of approximatively one Outside Diameter width insure convergence of the analysis for Jumpers and Spools. The spreadsheets developed have been made so to let the user free to choose the element length.

The *.INP file has been created taking into account the consideration above.(see Attachment 1 for a typical Abaqus file developed).

If more advanced analysis are required, usually in the bends, the use of thick beam section with brick or shell elements could be an option. Indeed the thickness of the pipe would then be more precisely described. Some convergence analysis on both type of 3D element have been carried.

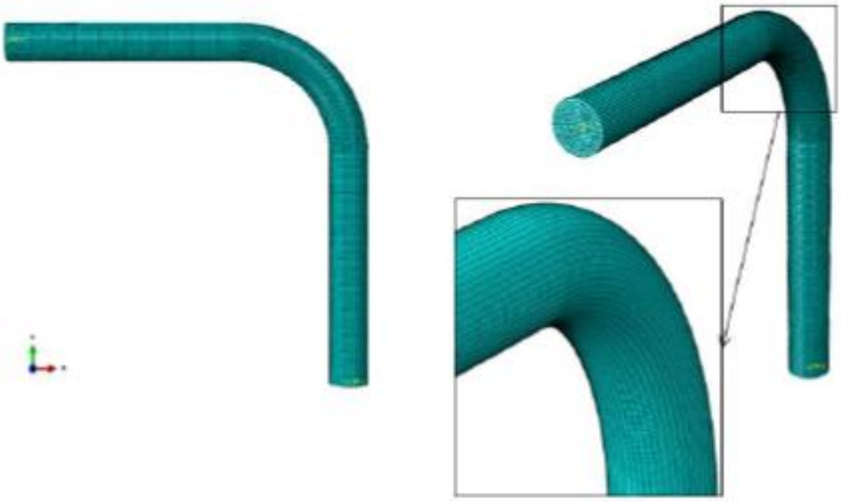


Figure 40. 3D bend Mesh with Shell Elements

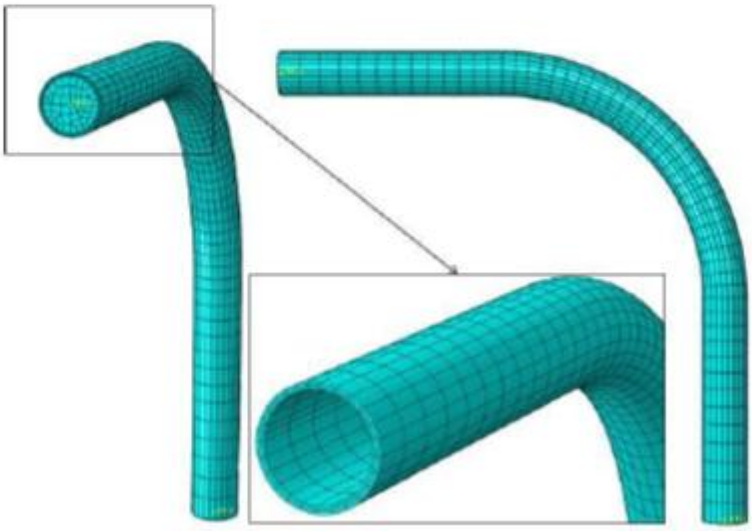


Figure 41. 3D bend Mesh with Brick Elements

Preliminary analyses have shown that for thin pipes the results are very similar, see Figure 42. On the other hand, for thick pipes, the solid 3D Brick elements are in general conservative with respect to Shell elements, as shown in Figure 43, being the difference in the order of 6%. Consequently 3D Brick (BRICK) elements should be preferred in the design of precise pipeline bends.

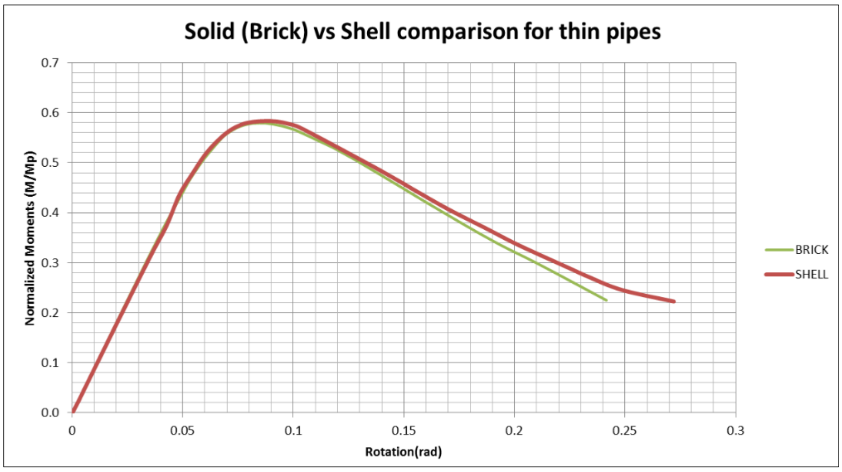


Figure 42. Brick vs Shell Comparaison - Results for thin pipes

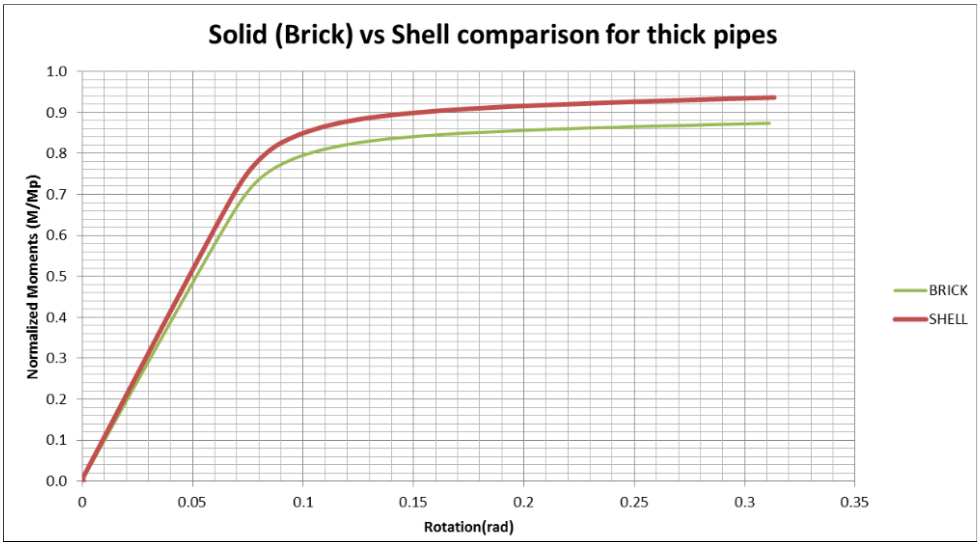


Figure 43. Brick vs Shell Comparaison - Results for thick pipes

The Abaqus *.ODB file enables us to verify that the Jumper model is correctly created. The checks conducted are:

- The geometry of the pipeline.
- The deformed shape under gravity load, wave load and imposed displacements.
- The reaction load RF3 at the connector (cf calculation note below)
- The rigidity of the connector

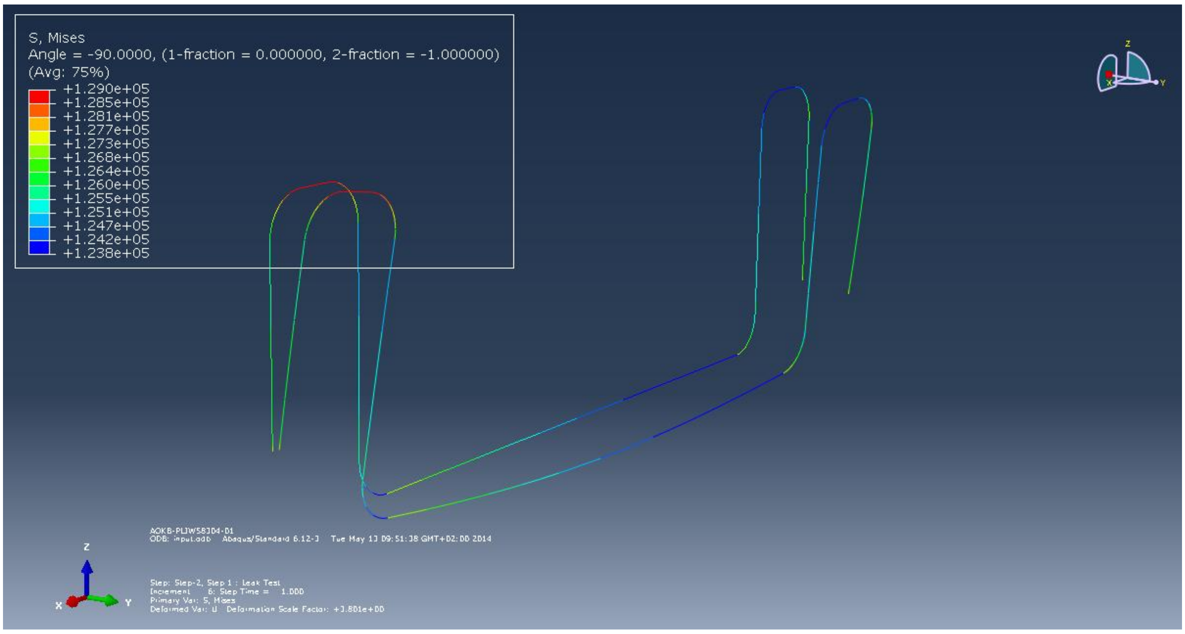


Figure 44. Jumper with an imposed displacement on ABAQUS

The gravity load case with the connector weights is used to check that the correct weight is applied on the structure. The reactions forces at both ends are extracted. Their values should be equal to the weight of the jumper with the connector loads.

Gravity case with connectors	RF1 (N)	RF3 (N)
Force at ends 1/2	7447	59287/59522

From RF3 value, we check that the weight is correctly applied :

$$RF3_{end_i} \approx Connector_{wgh_i} + \frac{(L * s_w)}{2}$$

With $or_{wgh_i} \approx 37000\ (N)$; $L \approx 60\ (m)$; $s_w \approx 0.858\ \left(\frac{KN}{m}\right)$

The abaqus file developed is embedding the complete range of imposed displacements i.e. metrology and fabrication tolerances as well as the expansions. Each step is relating to one imposed displacement at the extremity. This processing way is valid as long as the imposed displacements are not excessively high and imply plasticity of the structure, because of residual deformations.

4.2 INPUT SPREADSHEET

The purpose of the input spreadsheet (FORM-SSA-SFD-FLOWS-054-E) is:

- To generate jumpers models for both the FEA tools Abaqus and Autopipe.
- To create the range of imposed displacements at the extremities and to apply those conditions to the structures.
- To run the input files automatically in batch mode.

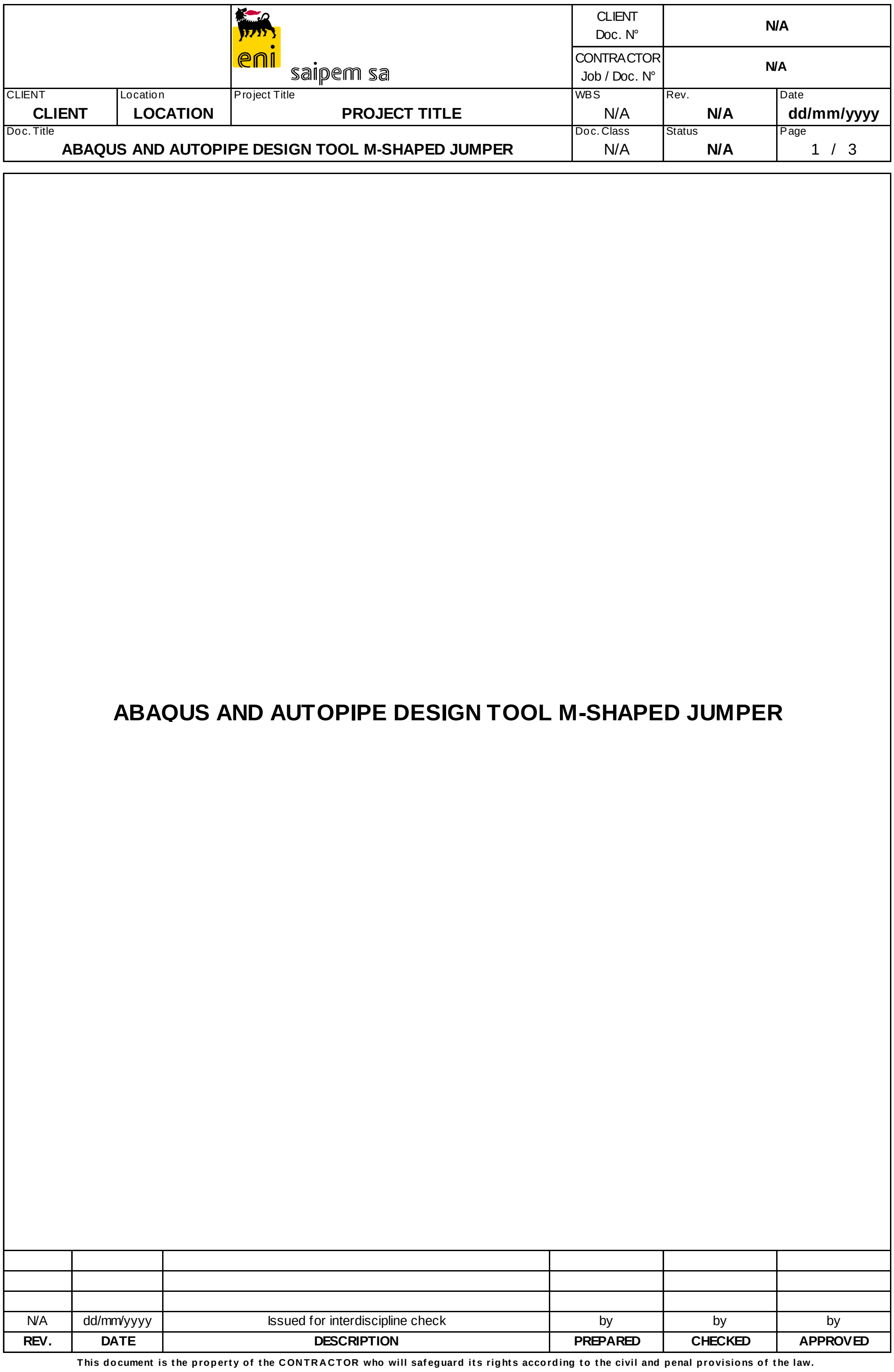
VBA code has been used to automatize the processing of the spreadsheet. At first the possibility of the spreadsheet only applied for the design of M-shaped plan jumpers on vertical support. Further developments will include 3D Jumpers and Spools lying on the seabed.

The input spreadsheet enables to design in the same action several Jumpers with 6 load cases each (As Landed, Hydrotest, Leak Test, Operating, Design and Shut Down). Buoyancy modules can be applied on every location on the structure. Both the Abaqus and Autopipe models are created by the spreadsheet.

Standard quality requirements of the Flowline Department of Saipem have been respected. The spreadsheet is composed of 7 worksheets:

COVER PAGE, REVISION HISTORY, INPUT, DISPL, INP, NTL, RESULTS.

1) “COVER PAGE” WORKSHEET



		eni saipem sa	CLIENT Doc. N°	N/A	
			CONTRACTOR Job / Doc. N°	N/A	
CLIENT **CLIENT**	Location **LOCATION**	Project Title **PROJECT TITLE**	WBS N/A	Rev. **N/A**	Date **dd/mm/yyyy**
Doc. Title **ABAQUS AND AUTOPIPE DESIGN TOOL M-SHAPED JUMPER**			Doc. Class N/A	Status **N/A**	Page 1 / 3

ABAQUS AND AUTOPIPE DESIGN TOOL M-SHAPED JUMPER

N/A	dd/mm/yyyy	Issued for interdiscipline check	by	by	by
REV.	**DATE**	**DESCRIPTION**	**PREPARED**	**CHECKED**	**APPROVED**

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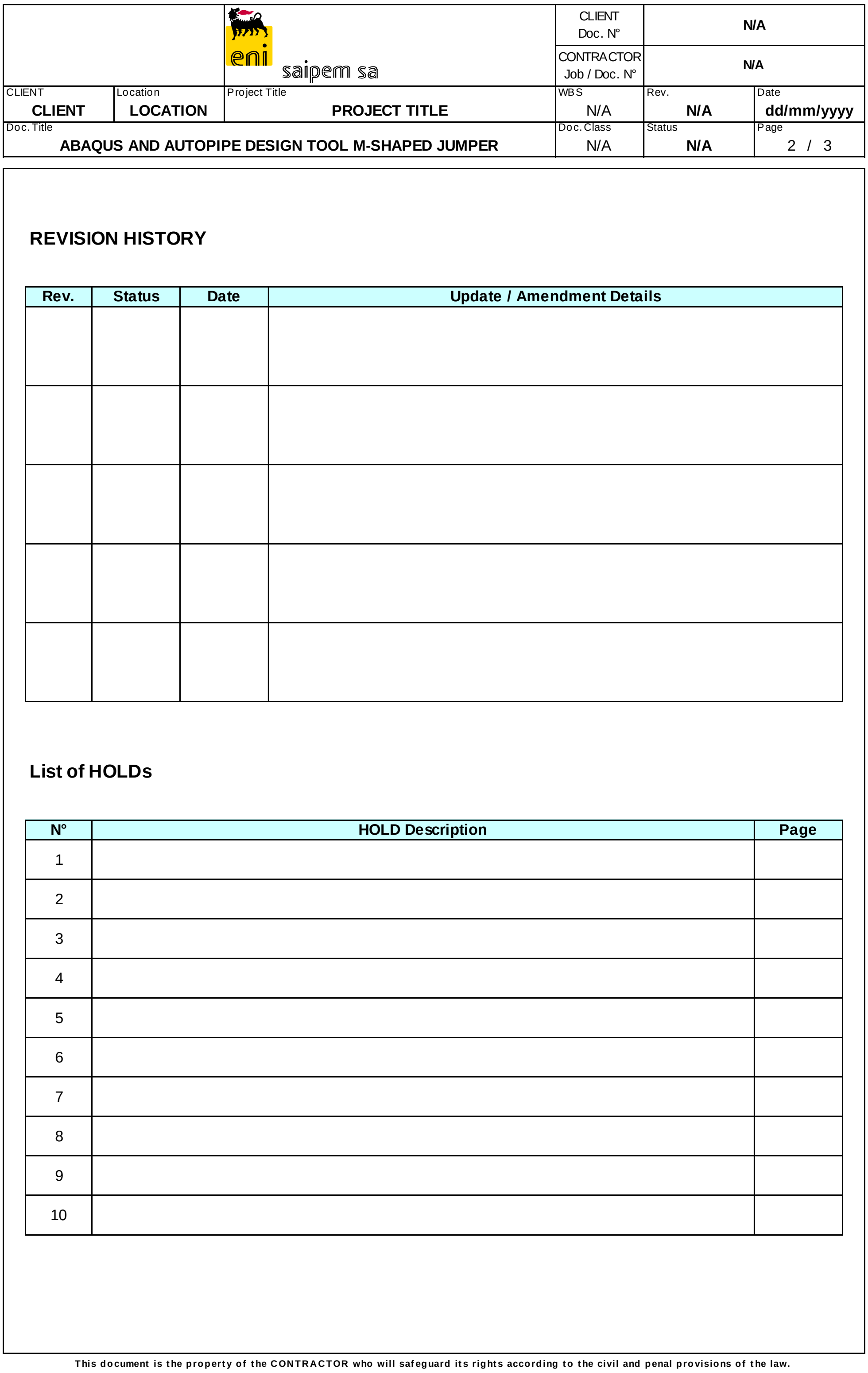
2) “REVISION HISTORY” WORKSHEET



		saipem sa	CLIENT Doc. N°	N/A	
			CONTRACTOR Job / Doc. N°	N/A	
CLIENT CLIENT	Location LOCATION	Project Title PROJECT TITLE	WBS N/A	Rev. N/A	Date dd/mm/yyyy
Doc. Title ABAQUS AND AUTOPIPE DESIGN TOOL M-SHAPED JUMPER			Doc. Class N/A	Status N/A	Page 2 / 3

REVISION HISTORY

Rev.	Status	Date	Update / Amendment Details

List of HOLDs

N°	HOLD Description	Page
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		

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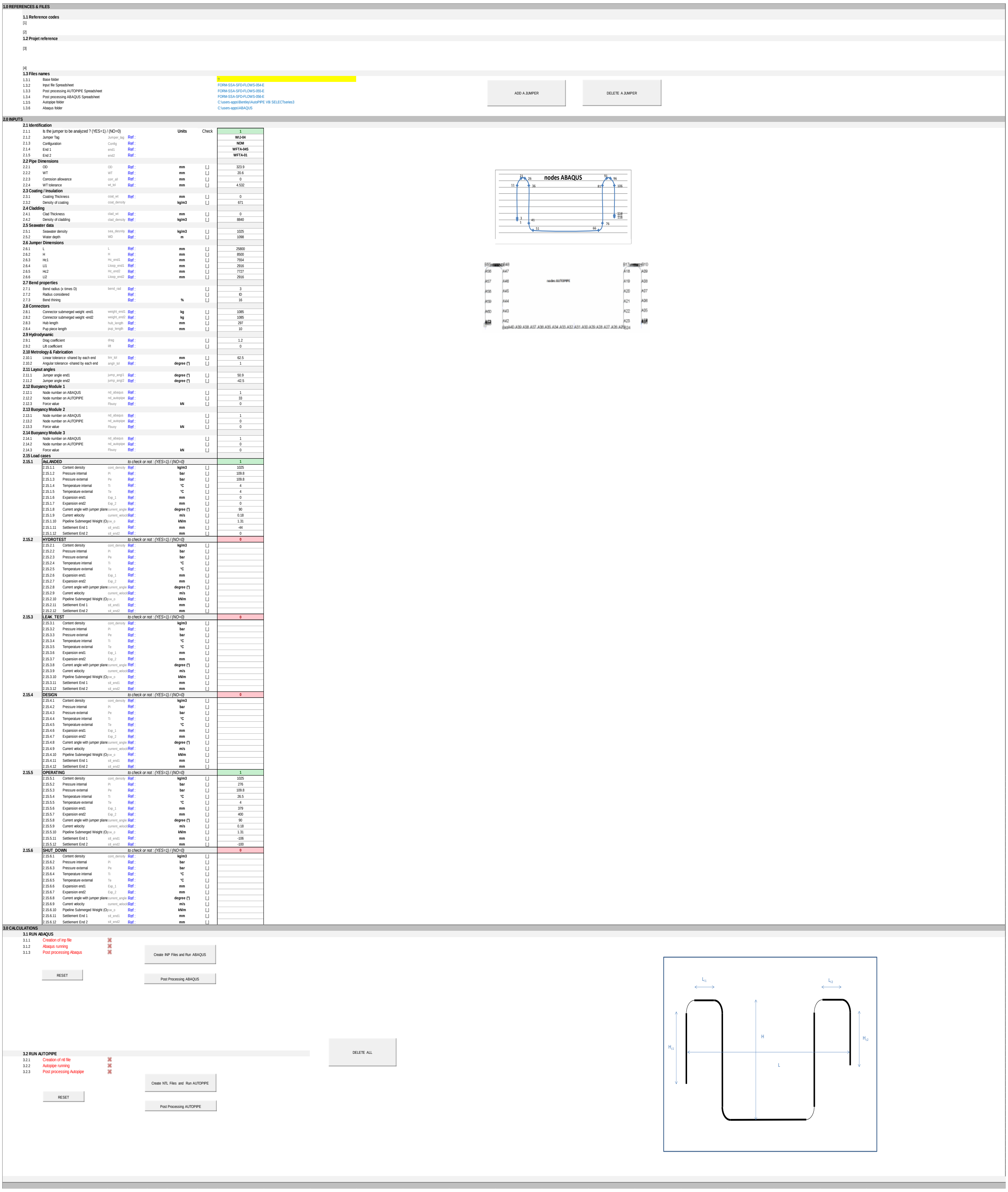
3) “INPUT” WORKSHEET



1.0 REFERENCES & FILES

1.1 Reference codes

[1]

[2]

1.2 Projet reference

[3]

[4]

1.3 Files names

1.3.1	Base folder	?
1.3.2	Input file Spreadsheet	FORM-SSA-SFD-FLOWS-054-E
1.3.3	Post processing AUTOPIPE Spreadsheet	FORM-SSA-SFD-FLOWS-055-E
1.3.4	Post processing ABAQUS Spreadsheet	FORM-SSA-SFD-FLOWS-056-E
1.3.5	Autopipe folder	C:\users-apps\Bentley\AutoPIPE V8i SELECTseries3
1.3.6	Abaqus folder	C:\users-apps\ABAQUS

2.0 INPUTS

				Units	Check	
2.1 Identification						
2.1.1	Is the jumper to be analyzed ? (YES=1) / (NO=0)					1
2.1.2	Jumper Tag	Jumper_tag	Ref :			WIJ-04
2.1.3	Configuration	Config	Ref :			NOM
2.1.4	End 1	end1	Ref :			WFTA-04S
2.1.5	End 2	end2	Ref :			WFTA-01
2.2 Pipe Dimensions						
2.2.1	OD	OD	Ref :	mm	☐	323.9
2.2.2	WT	WT	Ref :	mm	☐	20.6
2.2.3	Corrosion allowance	corr_all	Ref :	mm	☐	0
2.2.4	WT tolerance	wt_tol	Ref :	mm	☐	4.532
2.3 Coating / Insulation						
2.3.1	Coating Thickness	coat_wt	Ref :	mm	☐	0
2.3.2	Density of coating	coat_density		kg/m3	☐	671
2.4 Cladding						
2.4.1	Clad Thickness	clad_wt	Ref :	mm	☐	0
2.4.2	Density of cladding	clad_density	Ref :	kg/m3	☐	8840
2.5 Seawater data						
2.5.1	Seawater density	sea_desnity	Ref :	kg/m3	☐	1025
2.5.2	Water depth	WD	Ref :	m	☐	1098
2.6 Jumper Dimensions						
2.6.1	L	L	Ref :	mm	☐	25800
2.6.2	H	H	Ref :	mm	☐	8500
2.6.3	Hc1	Hc_end1	Ref :	mm	☐	7554
2.6.4	Ll1	Lloop_end1	Ref :	mm	☐	2916
2.6.5	Hc2	Hc_end2	Ref :	mm	☐	7727
2.6.6	Ll2	Lloop_end2	Ref :	mm	☐	2916
2.7 Bend properties						
2.7.1	Bend radius (x times D)	bend_rad	Ref :		☐	3
2.7.2	Radius considered		Ref :		☐	ID
2.7.3	Bend thining		Ref :	%	☐	16
2.8 Connectors						
2.8.1	Connector submerged weight -end1	weight_end1	Ref :	kg	☐	1085
2.8.2	Connector submerged weight -end2	weight_end2	Ref :	kg	☐	1085
2.8.3	Hub length	hub_length	Ref :	mm	☐	297
2.8.4	Pup piece length	pup_length	Ref :	mm	☐	10
2.9 Hydrodynamic						
2.9.1	Drag coefficient	drag	Ref :		☐	1.2
2.9.2	Lift coefficient	lift	Ref :		☐	0
2.10 Metrology & Fabrication						
2.10.1	Linear tolerance -shared by each end	linr_tol	Ref :	mm	☐	62.5
2.10.2	Angular tolerance -shared by each end	anglr_tol	Ref :	degree (°)	☐	1
2.11 Layout angles						
2.11.1	Jumper angle end1	jump_angl1	Ref :	degree (°)	☐	50.9
2.11.2	Jumper angle end2	jump_angl2	Ref :	degree (°)	☐	-42.5
2.12 Buoyancy Module 1						
2.12.1	Node number on ABAQUS	nd_abaqus	Ref :		☐	1
2.12.2	Node number on AUTOPIPE	nd_autopipe	Ref :		☐	33
2.12.3	Force value	Fbuoy	Ref :	kN	☐	0
2.13 Buoyancy Module 2						
2.13.1	Node number on ABAQUS	nd_abaqus	Ref :		☐	1
2.13.2	Node number on AUTOPIPE	nd_autopipe	Ref :		☐	0
2.13.3	Force value	Fbuoy	Ref :	kN	☐	0
2.14 Buoyancy Module 3						
2.14.1	Node number on ABAQUS	nd_abaqus	Ref :		☐	1
2.14.2	Node number on AUTOPIPE	nd_autopipe	Ref :		☐	0
2.14.3	Force value	Fbuoy	Ref :	kN	☐	0
2.15 Load cases						
2.15.1	**AsLANDED**		*to check or not : (YES=1) / (NO=0)*			1
2.15.1.1	Content density	cont_density	Ref :	kg/m3	☐	1025
2.15.1.2	Pressure internal	Pi	Ref :	bar	☐	109.8
2.15.1.3	Pressure external	Pe	Ref :	bar	☐	109.8
2.15.1.4	Temperature internal	Ti	Ref :	°C	☐	4
2.15.1.5	Temperature external	Te	Ref :	°C	☐	4
2.15.1.6	Expansion end1	Exp_1	Ref :	mm	☐	0
2.15.1.7	Expansion end2	Exp_2	Ref :	mm	☐	0
2.15.1.8	Current angle with jumper plane	current_angle	Ref :	degree (°)	☐	90
2.15.1.9	Current velocity	current_velocit	Ref :	m/s	☐	0.18
2.15.1.10	Pipeline Submerged Weight (O	sw_o	Ref :	kN/m	☐	1.31
2.15.1.11	Settlement End 1	stl_end1	Ref :	mm	☐	-44
2.15.1.12	Settlement End 2	stl_end2	Ref :	mm	☐	0
2.15.2	**HYDROTEST**		*to check or not : (YES=1) / (NO=0)*			0
2.15.2.1	Content density	cont_density	Ref :	kg/m3	☐	
2.15.2.2	Pressure internal	Pi	Ref :	bar	☐	
2.15.2.3	Pressure external	Pe	Ref :	bar	☐	
2.15.2.4	Temperature internal	Ti	Ref :	°C	☐	
2.15.2.5	Temperature external	Te	Ref :	°C	☐	
2.15.2.6	Expansion end1	Exp_1	Ref :	mm	☐	
2.15.2.7	Expansion end2	Exp_2	Ref :	mm	☐	
2.15.2.8	Current angle with jumper plane	current_angle	Ref :	degree (°)	☐	
2.15.2.9	Current velocity	current_velocit	Ref :	m/s	☐	
2.15.2.10	Pipeline Submerged Weight (O	sw_o	Ref :	kN/m	☐	
2.15.2.11	Settlement End 1	stl_end1	Ref :	mm	☐	
2.15.2.12	Settlement End 2	stl_end2	Ref :	mm	☐	
2.15.3	**LEAK_TEST**		*to check or not : (YES=1) / (NO=0)*			0
2.15.3.1	Content density	cont_density	Ref :	kg/m3	☐	
2.15.3.2	Pressure internal	Pi	Ref :	bar	☐	
2.15.3.3	Pressure external	Pe	Ref :	bar	☐	
2.15.3.4	Temperature internal	Ti	Ref :	°C	☐	
2.15.3.5	Temperature external	Te	Ref :	°C	☐	
2.15.3.6	Expansion end1	Exp_1	Ref :	mm	☐	
2.15.3.7	Expansion end2	Exp_2	Ref :	mm	☐	
2.15.3.8	Current angle with jumper plane	current_angle	Ref :	degree (°)	☐	
2.15.3.9	Current velocity	current_velocit	Ref :	m/s	☐	
2.15.3.10	Pipeline Submerged Weight (O	sw_o	Ref :	kN/m	☐	
2.15.3.11	Settlement End 1	stl_end1	Ref :	mm	☐	
2.15.3.12	Settlement End 2	stl_end2	Ref :	mm	☐	
2.15.4	**DESIGN**		*to check or not : (YES=1) / (NO=0)*			0
2.15.4.1	Content density	cont_density	Ref :	kg/m3	☐	
2.15.4.2	Pressure internal	Pi	Ref :	bar	☐	
2.15.4.3	Pressure external	Pe	Ref :	bar	☐	
2.15.4.4	Temperature internal	Ti	Ref :	°C	☐	
2.15.4.5	Temperature external	Te	Ref :	°C	☐	
2.15.4.6	Expansion end1	Exp_1	Ref :	mm	☐	
2.15.4.7	Expansion end2	Exp_2	Ref :	mm	☐	
2.15.4.8	Current angle with jumper plane	current_angle	Ref :	degree (°)	☐	
2.15.4.9	Current velocity	current_velocit	Ref :	m/s	☐	
2.15.4.10	Pipeline Submerged Weight (O	sw_o	Ref :	kN/m	☐	
2.15.4.11	Settlement End 1	stl_end1	Ref :	mm	☐	
2.15.4.12	Settlement End 2	stl_end2	Ref :	mm	☐	
2.15.5	**OPERATING**		*to check or not : (YES=1) / (NO=0)*			1
2.15.5.1	Content density	cont_density	Ref :	kg/m3	☐	1025
2.15.5.2	Pressure internal	Pi	Ref :	bar	☐	276
2.15.5.3	Pressure external	Pe	Ref :	bar	☐	109.8
2.15.5.4	Temperature internal	Ti	Ref :	°C	☐	26.5
2.15.5.5	Temperature external	Te	Ref :	°C	☐	4
2.15.5.6	Expansion end1	Exp_1	Ref :	mm	☐	379
2.15.5.7	Expansion end2	Exp_2	Ref :	mm	☐	400
2.15.5.8	Current angle with jumper plane	current_angle	Ref :	degree (°)	☐	90
2.15.5.9	Current velocity	current_velocit	Ref :	m/s	☐	0.18
2.15.5.10	Pipeline Submerged Weight (O	sw_o	Ref :	kN/m	☐	1.31
2.15.5.11	Settlement End 1	stl_end1	Ref :	mm	☐	-106
2.15.5.12	Settlement End 2	stl_end2	Ref :	mm	☐	-100
2.15.6	**SHUT_DOWN**		*to check or not : (YES=1) / (NO=0)*			0
2.15.6.1	Content density	cont_density	Ref :	kg/m3	☐	
2.15.6.2	Pressure internal	Pi	Ref :	bar	☐	
2.15.6.3	Pressure external	Pe	Ref :	bar	☐	
2.15.6.4	Temperature internal	Ti	Ref :	°C	☐	
2.15.6.5	Temperature external	Te	Ref :	°C	☐	
2.15.6.6	Expansion end1	Exp_1	Ref :	mm	☐	
2.15.6.7	Expansion end2	Exp_2	Ref :	mm	☐	
2.15.6.8	Current angle with jumper plane	current_angle	Ref :	degree (°)	☐	
2.15.6.9	Current velocity	current_velocit	Ref :	m/s	☐	
2.15.6.10	Pipeline Submerged Weight (O	sw_o	Ref :	kN/m	☐	
2.15.6.11	Settlement End 1	stl_end1	Ref :	mm	☐	
2.15.6.12	Settlement End 2	stl_end2	Ref :	mm	☐	

3.0 CALCULATIONS

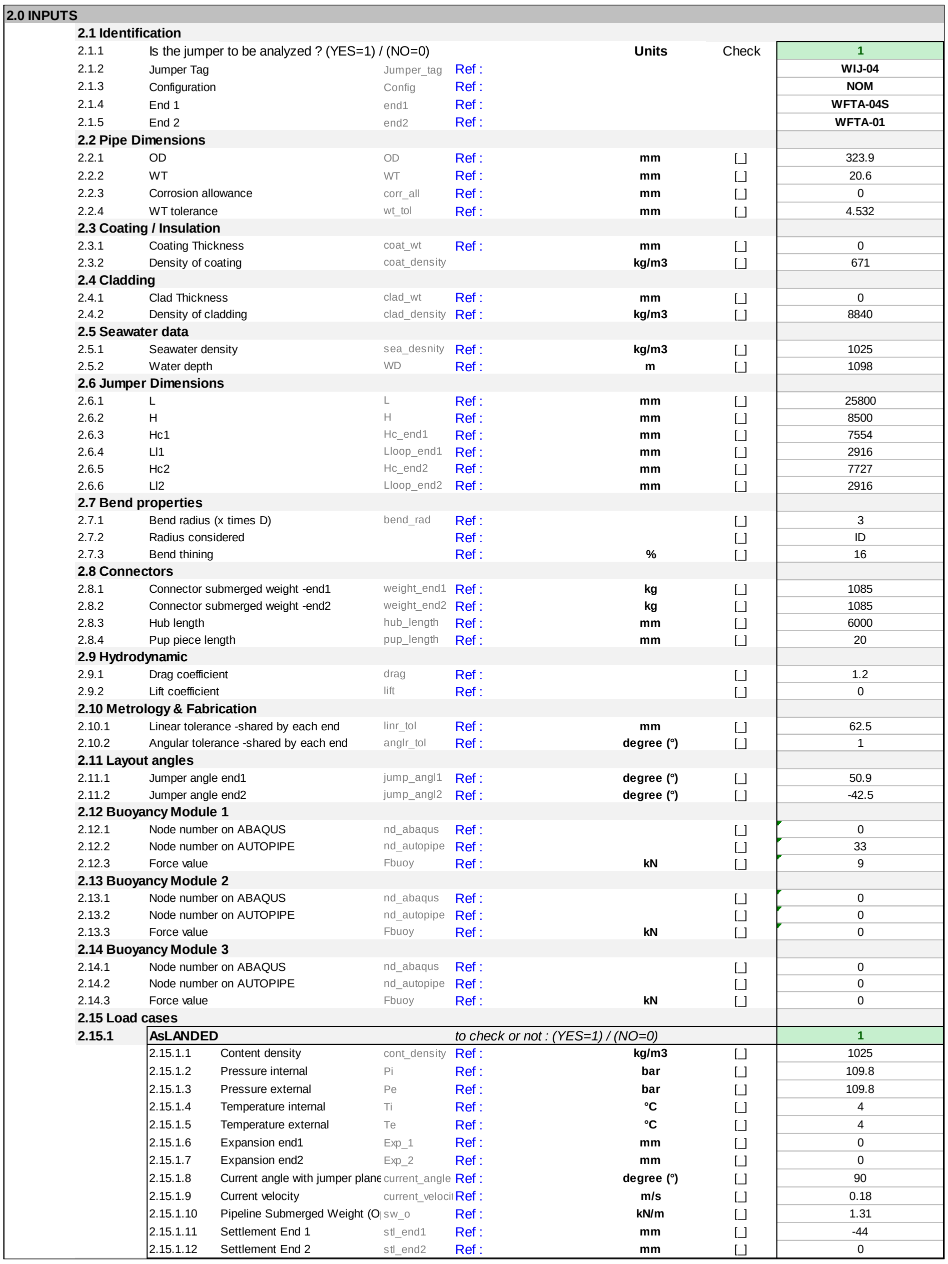
3.1 RUN ABAQUS

3.1.1	Creation of inp file	☒
3.1.2	Abaqus running	☒
3.1.3	Post processing Abaqus	☒

3.2 RUN AUTOPIPE

3.2.1	Creation of ntl file	☒
3.2.2	Autopipe running	☒
3.2.3	Post processing Autopipe	☒

A better view of the spreadsheet is given here below :



2.0 INPUTS						
2.1 Identification						
2.1.1	Is the jumper to be analyzed ? (YES=1) / (NO=0)			**Units**	Check	1
2.1.2	Jumper Tag	Jumper_tag	Ref :			**WIJ-04**
2.1.3	Configuration	Config	Ref :			**NOM**
2.1.4	End 1	end1	Ref :			**WFTA-04S**
2.1.5	End 2	end2	Ref :			**WFTA-01**
2.2 Pipe Dimensions						
2.2.1	OD	OD	Ref :	**mm**	☐	323.9
2.2.2	WT	WT	Ref :	**mm**	☐	20.6
2.2.3	Corrosion allowance	corr_all	Ref :	**mm**	☐	0
2.2.4	WT tolerance	wt_tol	Ref :	**mm**	☐	4.532
2.3 Coating / Insulation						
2.3.1	Coating Thickness	coat_wt	Ref :	**mm**	☐	0
2.3.2	Density of coating	coat_density		**kg/m3**	☐	671
2.4 Cladding						
2.4.1	Clad Thickness	clad_wt	Ref :	**mm**	☐	0
2.4.2	Density of cladding	clad_density	Ref :	**kg/m3**	☐	8840
2.5 Seawater data						
2.5.1	Seawater density	sea_desnity	Ref :	**kg/m3**	☐	1025
2.5.2	Water depth	WD	Ref :	**m**	☐	1098
2.6 Jumper Dimensions						
2.6.1	L	L	Ref :	**mm**	☐	25800
2.6.2	H	H	Ref :	**mm**	☐	8500
2.6.3	Hc1	Hc_end1	Ref :	**mm**	☐	7554
2.6.4	Ll1	Lloop_end1	Ref :	**mm**	☐	2916
2.6.5	Hc2	Hc_end2	Ref :	**mm**	☐	7727
2.6.6	Ll2	Lloop_end2	Ref :	**mm**	☐	2916
2.7 Bend properties						
2.7.1	Bend radius (x times D)	bend_rad	Ref :		☐	3
2.7.2	Radius considered		Ref :		☐	ID
2.7.3	Bend thining		Ref :	**%**	☐	16
2.8 Connectors						
2.8.1	Connector submerged weight -end1	weight_end1	Ref :	**kg**	☐	1085
2.8.2	Connector submerged weight -end2	weight_end2	Ref :	**kg**	☐	1085
2.8.3	Hub length	hub_length	Ref :	**mm**	☐	6000
2.8.4	Pup piece length	pup_length	Ref :	**mm**	☐	20
2.9 Hydrodynamic						
2.9.1	Drag coefficient	drag	Ref :		☐	1.2
2.9.2	Lift coefficient	lift	Ref :		☐	0
2.10 Metrology & Fabrication						
2.10.1	Linear tolerance -shared by each end	linr_tol	Ref :	**mm**	☐	62.5
2.10.2	Angular tolerance -shared by each end	anglr_tol	Ref :	**degree (°)**	☐	1
2.11 Layout angles						
2.11.1	Jumper angle end1	jump_angl1	Ref :	**degree (°)**	☐	50.9
2.11.2	Jumper angle end2	jump_angl2	Ref :	**degree (°)**	☐	-42.5
2.12 Buoyancy Module 1						
2.12.1	Node number on ABAQUS	nd_abaqus	Ref :		☐	0
2.12.2	Node number on AUTOPIPE	nd_autopipe	Ref :		☐	33
2.12.3	Force value	Fbuoy	Ref :	**kN**	☐	9
2.13 Buoyancy Module 2						
2.13.1	Node number on ABAQUS	nd_abaqus	Ref :		☐	0
2.13.2	Node number on AUTOPIPE	nd_autopipe	Ref :		☐	0
2.13.3	Force value	Fbuoy	Ref :	**kN**	☐	0
2.14 Buoyancy Module 3						
2.14.1	Node number on ABAQUS	nd_abaqus	Ref :		☐	0
2.14.2	Node number on AUTOPIPE	nd_autopipe	Ref :		☐	0
2.14.3	Force value	Fbuoy	Ref :	**kN**	☐	0
2.15 Load cases						
2.15.1	**AsLANDED**		*to check or not : (YES=1) / (NO=0)*			1
2.15.1.1	Content density	cont_density	Ref :	**kg/m3**	☐	1025
2.15.1.2	Pressure internal	Pi	Ref :	**bar**	☐	109.8
2.15.1.3	Pressure external	Pe	Ref :	**bar**	☐	109.8
2.15.1.4	Temperature internal	Ti	Ref :	**°C**	☐	4
2.15.1.5	Temperature external	Te	Ref :	**°C**	☐	4
2.15.1.6	Expansion end1	Exp_1	Ref :	**mm**	☐	0
2.15.1.7	Expansion end2	Exp_2	Ref :	**mm**	☐	0
2.15.1.8	Current angle with jumper plane	current_angle	Ref :	**degree (°)**	☐	90
2.15.1.9	Current velocity	current_veloci	Ref :	**m/s**	☐	0.18
2.15.1.10	Pipeline Submerged Weight (O	sw_o	Ref :	**kN/m**	☐	1.31
2.15.1.11	Settlement End 1	stl_end1	Ref :	**mm**	☐	-44
2.15.1.12	Settlement End 2	stl_end2	Ref :	**mm**	☐	0

Figure 45. Input Spreadsheet

Each column of the spreadsheet can be used for a jumper. The input variables needed to be entered are:

2.0 INPUTS subdivisions	Descriptions
IDENTIFICATION	Allows user to provide names for : Jumper Tag, Configuration, End 1, End 2.
PIPE DIMENSIONS	OD, WT, Corrosion Allowance (CA),WT tolerance
COATING / INSULATION	Coating Thickness, Density coating
CLADDING	Cladding Thickness, Density cladding

2.0 INPUTS subdivisions	Descriptions
SEA WATER DATA	Seawater density, Water depth
JUMPER DIMENSIONS	L, H, HC1, Ll1, HC2, Ll2 (see the Figure 45)
BEND PROPERTIES	Bend radius (number of times OD or ID), Bend thinning in %
CONNECTORS	Connectors Submerged weights at both extremities, Hub length, Pup piece lengths
HYDRODYNAMIC	Drag coefficient, Lift coefficient
METROLOGY & FABRICATION	Linear tolerances, Angular tolerances
LAYOUT ANGLES	Line angle with jumper at end 1, Line angle with jumper at end 2 (used to calculate displacement caused by flowline in jumper coordinate system).
BUOYANCY MODULES	Node number, Vertical up lift force
LOAD CASES	Content density, PI, PE, TI, TE, Expansions, Current velocity, Current angle, Pipeline Submerged Weight, Settlement at both the extremities

Jumper Dimensions are entered according to a pre-defined scheme of the M-shaped vertical jumper.

JUMPER DIMENSIONS (see drawing below)			
L	(2.6.1)	**[mm]**	Indicate the complete length of the jumper
H	(2.6.2)	**[mm]**	Indicate the height of the inner U shape of the jumper
Hc1	(2.6.3)	**[mm]**	Indicate the height of the straight length 1
Ll1	(2.6.4)	**[mm]**	Indicate the length of the first loop
Hc2	(2.6.5)	**[mm]**	Indicate the height of the straight length 2
Ll2	(2.6.6)	**[mm]**	Indicate the length of the second loop

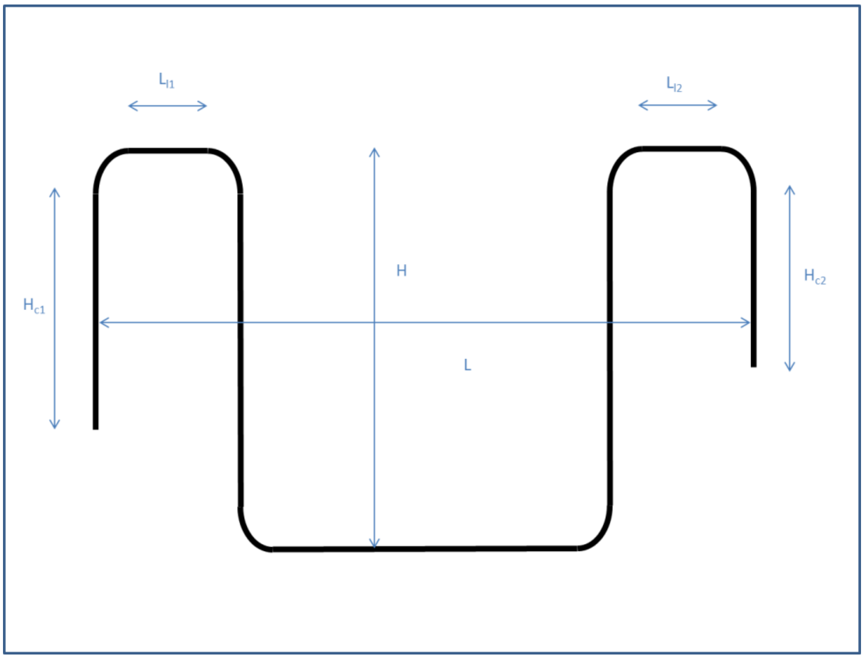
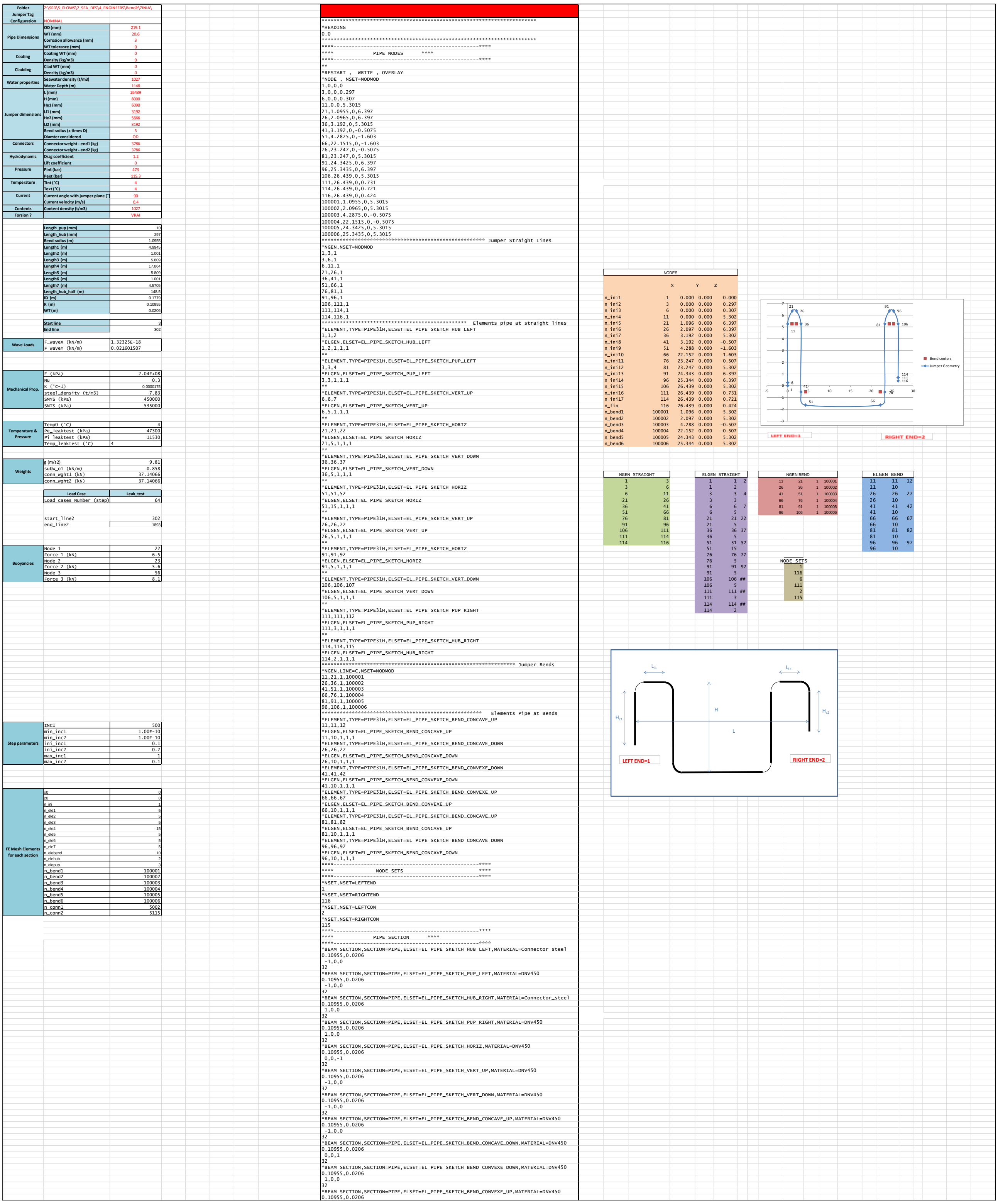


Figure 46. Jumper Dimensions

The dimensions of the jumper are entered in the spreadsheet according to the sketch above. Additionally the lengths of the pup piece and the hub must be filled in.

4) "INP" WORKSHEET



Folder	Z:\SFD\5_FLOWS\2_SEA_DES\4_ENGINEERS\Benoît\ZINIA\	
Jumper Tag		
Configuration	NOMINAL	
Pipe Dimensions	OD (mm)	219.1
	WT (mm)	20.6
	Corrosion allowance (mm)	3
	WT tolerance (mm)	0
Coating	Coating WT (mm)	0
	Density (kg/m3)	0
Cladding	Clad WT (mm)	0
	Density (kg/m3)	0
Water properties	Seawater density (t/m3)	1027
	Water Depth (m)	1148
Jumper dimensions	L (mm)	26439
	H (mm)	8000
	He1 (mm)	6090
	Ll1 (mm)	3192
	He2 (mm)	5666
	Ll2 (mm)	3192
	Bend radius (x times D)	5
	Diamter considered	OD
Connectors	Connector weight - end1 (kg)	3786
	Connector weight - end2 (kg)	3786
Hydrodynamic	Drag coefficient	1.2
	Lift coefficient	0
Pressure	Pint (bar)	473
	Pext (bar)	115.3
Temperature	Tint (°C)	4
	Text (°C)	4
Current	Current angle with jumper plane (°	90
	Current velocity (m/s)	0.4
Contents	Content density (t/m3)	1027
Torsion ?		VRAI

Length_pup (mm)	10
Length_hub (mm)	297
Bend radius (m)	1.0955
Length1 (m)	4.9945
Length2 (m)	1.001
Length3 (m)	5.809
Length4 (m)	17.864
Length5 (m)	5.809
Length6 (m)	1.001
Length7 (m)	4.5705
Length_hub_half (m)	148.5
ID (m)	0.1779
R (m)	0.10955
WT (m)	0.0206

Start line	3
End line	302

Wave Loads	F_waveX (kN/m)	1.32325E-18
	F_waveY (kN/m)	0.021601507
Mechanical Prop.	E (kPa)	2.04E+08
	Nu	0.3
	K (°C-1)	0.0000175
	steel_density (t/m3)	7.83
	SMYS (kPa)	450000
	SMTS (kPa)	535000
Temperature & Pressure	Temp0 (°C)	4
	Pe_leaktest (kPa)	47300
	Pi_leaktest (kPa)	11530
	Temp_leaktest (°C)	4
Weights	g (m/s2)	9.81
	subW_o1 (kN/m)	0.858
	conn_wght1 (kN)	37.14066
	conn_wght2 (kN)	37.14066

Load Case	Leak_test
Load cases Number (step)	64

start_line2	302
end_line2	1893

Buoyancies	Node 1	22
	Force 1 (kN)	6.5
	Node 2	23
	Force 2 (kN)	5.6
	Node 3	56
	Force 3 (kN)	8.1
Step parameters	INC1	500
	min_inc1	1.00E-10
	min_inc2	1.00E-10
	ini_inc1	0.1
	ini_inc2	0.2
	max_inc1	1
	max_inc2	0.1
FE Mesh Elements for each section	x0	0
	z0	0
	n_ini	1
	n_ele1	5
	n_ele2	5
	n_ele3	5
	n_ele4	15
	n_ele5	5
	n_ele6	5
	n_ele7	5
	n_elebend	10
	n_elehub	2
	n_elepup	3
	n_bend1	100001
	n_bend2	100002
	n_bend3	100003
	n_bend4	100004
	n_bend5	100005
	n_bend6	100006
	n_conn1	5002
	n_conn2	5115

```
**********************************************************************
*HEADING
0.0
**********************************************************************
****------------------------------------------------****
****              PIPE NODES        ****
****------------------------------------------------****
**
*RESTART ,  WRITE , OVERLAY
*NODE , NSET=NODMOD
1,0,0,0
3,0,0,0.297
6,0,0,0.307
11,0,0,5.3015
21,1.0955,0,6.397
26,2.0965,0,6.397
36,3.192,0,5.3015
41,3.192,0,-0.5075
51,4.2875,0,-1.603
66,22.1515,0,-1.603
76,23.247,0,-0.5075
81,23.247,0,5.3015
91,24.3425,0,6.397
96,25.3435,0,6.397
106,26.439,0,5.3015
111,26.439,0,0.731
114,26.439,0,0.721
116,26.439,0,0.424
100001,1.0955,0,5.3015
100002,2.0965,0,5.3015
100003,4.2875,0,-0.5075
100004,22.1515,0,-0.5075
100005,24.3425,0,5.3015
100006,25.3435,0,5.3015
****************************************************** Jumper Straight Lines
*NGEN,NSET=NODMOD
1,3,1
3,6,1
6,11,1
21,26,1
36,41,1
51,66,1
76,81,1
91,96,1
106,111,1
111,114,1
114,116,1
************************************************  Elements pipe at straight lines
*ELEMENT,TYPE=PIPE31H,ELSET=EL_PIPE_SKETCH_HUB_LEFT
1,1,2
*ELGEN,ELSET=EL_PIPE_SKETCH_HUB_LEFT
1,2,1,1,1
**
*ELEMENT,TYPE=PIPE31H,ELSET=EL_PIPE_SKETCH_PUP_LEFT
3,3,4
*ELGEN,ELSET=EL_PIPE_SKETCH_PUP_LEFT
3,3,1,1,1
**
*ELEMENT,TYPE=PIPE31H,ELSET=EL_PIPE_SKETCH_VERT_UP
6,6,7
*ELGEN,ELSET=EL_PIPE_SKETCH_VERT_UP
6,5,1,1,1
**
*ELEMENT,TYPE=PIPE31H,ELSET=EL_PIPE_SKETCH_HORIZ
21,21,22
*ELGEN,ELSET=EL_PIPE_SKETCH_HORIZ
21,5,1,1,1
**
*ELEMENT,TYPE=PIPE31H,ELSET=EL_PIPE_SKETCH_VERT_DOWN
36,36,37
*ELGEN,ELSET=EL_PIPE_SKETCH_VERT_DOWN
36,5,1,1,1
**
*ELEMENT,TYPE=PIPE31H,ELSET=EL_PIPE_SKETCH_HORIZ
51,51,52
*ELGEN,ELSET=EL_PIPE_SKETCH_HORIZ
51,15,1,1,1
**
*ELEMENT,TYPE=PIPE31H,ELSET=EL_PIPE_SKETCH_VERT_UP
76,76,77
*ELGEN,ELSET=EL_PIPE_SKETCH_VERT_UP
76,5,1,1,1
**
*ELEMENT,TYPE=PIPE31H,ELSET=EL_PIPE_SKETCH_HORIZ
91,91,92
*ELGEN,ELSET=EL_PIPE_SKETCH_HORIZ
91,5,1,1,1
**
*ELEMENT,TYPE=PIPE31H,ELSET=EL_PIPE_SKETCH_VERT_DOWN
106,106,107
*ELGEN,ELSET=EL_PIPE_SKETCH_VERT_DOWN
106,5,1,1,1
**
*ELEMENT,TYPE=PIPE31H,ELSET=EL_PIPE_SKETCH_PUP_RIGHT
111,111,112
*ELGEN,ELSET=EL_PIPE_SKETCH_PUP_RIGHT
111,3,1,1,1
**
*ELEMENT,TYPE=PIPE31H,ELSET=EL_PIPE_SKETCH_HUB_RIGHT
114,114,115
*ELGEN,ELSET=EL_PIPE_SKETCH_HUB_RIGHT
114,2,1,1,1
**************************************************************** Jumper Bends
*NGEN,LINE=C,NSET=NODMOD
11,21,1,100001
26,36,1,100002
41,51,1,100003
66,76,1,100004
81,91,1,100005
96,106,1,100006
*****************************************************   Elements Pipe at Bends
*ELEMENT,TYPE=PIPE31H,ELSET=EL_PIPE_SKETCH_BEND_CONCAVE_UP
11,11,12
*ELGEN,ELSET=EL_PIPE_SKETCH_BEND_CONCAVE_UP
11,10,1,1,1
*ELEMENT,TYPE=PIPE31H,ELSET=EL_PIPE_SKETCH_BEND_CONCAVE_DOWN
26,26,27
*ELGEN,ELSET=EL_PIPE_SKETCH_BEND_CONCAVE_DOWN
26,10,1,1,1
*ELEMENT,TYPE=PIPE31H,ELSET=EL_PIPE_SKETCH_BEND_CONVEXE_DOWN
41,41,42
*ELGEN,ELSET=EL_PIPE_SKETCH_BEND_CONVEXE_DOWN
41,10,1,1,1
*ELEMENT,TYPE=PIPE31H,ELSET=EL_PIPE_SKETCH_BEND_CONVEXE_UP
66,66,67
*ELGEN,ELSET=EL_PIPE_SKETCH_BEND_CONVEXE_UP
66,10,1,1,1
*ELEMENT,TYPE=PIPE31H,ELSET=EL_PIPE_SKETCH_BEND_CONCAVE_UP
81,81,82
*ELGEN,ELSET=EL_PIPE_SKETCH_BEND_CONCAVE_UP
81,10,1,1,1
*ELEMENT,TYPE=PIPE31H,ELSET=EL_PIPE_SKETCH_BEND_CONCAVE_DOWN
96,96,97
*ELGEN,ELSET=EL_PIPE_SKETCH_BEND_CONCAVE_DOWN
96,10,1,1,1
****------------------------------------------------****
****              NODE SETS                          ****
****------------------------------------------------****
*NSET,NSET=LEFTEND
1
*NSET,NSET=RIGHTEND
116
*NSET,NSET=LEFTCON
2
*NSET,NSET=RIGHTCON
115
****------------------------------------------------****
****              PIPE SECTION        ****
****------------------------------------------------****
*BEAM SECTION,SECTION=PIPE,ELSET=EL_PIPE_SKETCH_HUB_LEFT,MATERIAL=Connector_steel
0.10955,0.0206
 -1,0,0
32
*BEAM SECTION,SECTION=PIPE,ELSET=EL_PIPE_SKETCH_PUP_LEFT,MATERIAL=DNV450
0.10955,0.0206
 -1,0,0
32
*BEAM SECTION,SECTION=PIPE,ELSET=EL_PIPE_SKETCH_HUB_RIGHT,MATERIAL=Connector_steel
0.10955,0.0206
 1,0,0
32
*BEAM SECTION,SECTION=PIPE,ELSET=EL_PIPE_SKETCH_PUP_RIGHT,MATERIAL=DNV450
0.10955,0.0206
 1,0,0
32
*BEAM SECTION,SECTION=PIPE,ELSET=EL_PIPE_SKETCH_HORIZ,MATERIAL=DNV450
0.10955,0.0206
 0,0,-1
32
*BEAM SECTION,SECTION=PIPE,ELSET=EL_PIPE_SKETCH_VERT_UP,MATERIAL=DNV450
0.10955,0.0206
 -1,0,0
32
*BEAM SECTION,SECTION=PIPE,ELSET=EL_PIPE_SKETCH_VERT_DOWN,MATERIAL=DNV450
0.10955,0.0206
 -1,0,0
32
*BEAM SECTION,SECTION=PIPE,ELSET=EL_PIPE_SKETCH_BEND_CONCAVE_UP,MATERIAL=DNV450
0.10955,0.0206
 -1,0,0
32
*BEAM SECTION,SECTION=PIPE,ELSET=EL_PIPE_SKETCH_BEND_CONCAVE_DOWN,MATERIAL=DNV450
0.10955,0.0206
 0,0,1
32
*BEAM SECTION,SECTION=PIPE,ELSET=EL_PIPE_SKETCH_BEND_CONVEXE_DOWN,MATERIAL=DNV450
0.10955,0.0206
 1,0,0
32
*BEAM SECTION,SECTION=PIPE,ELSET=EL_PIPE_SKETCH_BEND_CONVEXE_UP,MATERIAL=DNV450
0.10955,0.0206
```

NODES

		X	Y	Z
n_ini1	1	0.000	0.000	0.000
n_ini2	3	0.000	0.000	0.297
n_ini3	6	0.000	0.000	0.307
n_ini4	11	0.000	0.000	5.302
n_ini5	21	1.096	0.000	6.397
n_ini6	26	2.097	0.000	6.397
n_ini7	36	3.192	0.000	5.302
n_ini8	41	3.192	0.000	-0.507
n_ini9	51	4.288	0.000	-1.603
n_ini10	66	22.152	0.000	-1.603
n_ini11	76	23.247	0.000	-0.507
n_ini12	81	23.247	0.000	5.302
n_ini13	91	24.343	0.000	6.397
n_ini14	96	25.344	0.000	6.397
n_ini15	106	26.439	0.000	5.302
n_ini16	111	26.439	0.000	0.731
n_ini17	114	26.439	0.000	0.721
n_fin	116	26.439	0.000	0.424
n_bend1	100001	1.096	0.000	5.302
n_bend2	100002	2.097	0.000	5.302
n_bend3	100003	4.288	0.000	-0.507
n_bend4	100004	22.152	0.000	-0.507
n_bend5	100005	24.343	0.000	5.302
n_bend6	100006	25.344	0.000	5.302

NGEN STRAIGHT	
1	3
3	6
6	11
21	26
36	41
51	66
76	81
91	96
106	111
111	114
114	116

ELGEN STRAIGHT		
1	1	2
1	2	
3	3	4
3	3	
6	6	7
6	5	
21	21	22
21	5	
36	36	37
36	5	
51	51	52
51	15	
76	76	77
76	5	
91	91	92
91	5	
106	106	##
106	5	
111	111	##
111	3	
114	114	##
114	2	

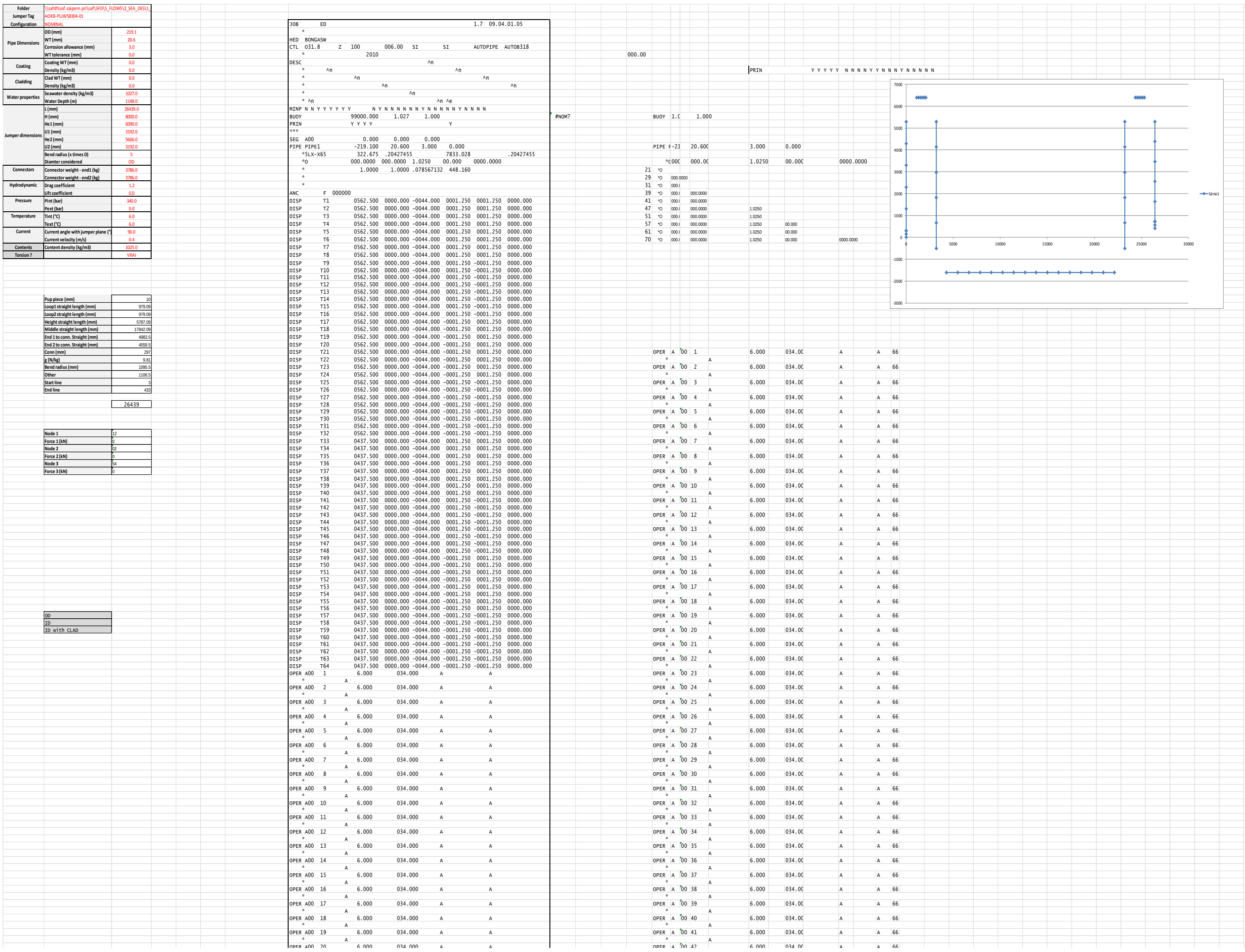
NGEN BEND			
11	21	1	100001
26	36	1	100002
41	51	1	100003
66	76	1	100004
81	91	1	100005
96	106	1	100006

NODE SETS
1
116
6
111
2
115

ELGEN BEND		
11	11	12
11	10	
26	26	27
26	10	
41	41	42
41	10	
66	66	67
66	10	
81	81	82
81	10	
96	96	97
96	10	

This excel worksheet is responsible of the generation of the Abaqus *.INP file starting from the input variables. Nodes coordinates, Pressure and Temperature conditions as well as Load Cases configurations are created by this worksheet using excel functions.

3) “NTL” WORKSHEET



Folder	\\safdfssaf.saipem.pri\saf\SFD\5_FLOWS\2_SEA_DES\1_	
Jumper Tag	AOKB-PLJW58304-01	
Configuration	NOMINAL	
Pipe Dimensions	OD (mm)	219.1
	WT (mm)	20.6
	Corrosion allowance (mm)	3.0
	WT tolerance (mm)	0.0
Coating	Coating WT (mm)	0.0
	Density (kg/m3)	0.0
Cladding	Clad WT (mm)	0.0
	Density (kg/m3)	0.0
Water properties	Seawater density (kg/m3)	1027.0
	Water Depth (m)	1148.0
Jumper dimensions	L (mm)	26439.0
	H (mm)	8000.0
	He1 (mm)	6090.0
	Ll1 (mm)	3192.0
	He2 (mm)	5666.0
	Ll2 (mm)	3192.0
	Bend radius (x times D)	5
	Diamter considered	OD
Connectors	Connector weight - end1 (kg)	3786.0
	Connector weight - end2 (kg)	3786.0
Hydrodynamic	Drag coefficient	1.2
	Lift coefficient	0.0
Pressure	Pint (bar)	340.0
	Pext (bar)	0.0
Temperature	Tint (°C)	6.0
	Text (°C)	6.0
Current	Current angle with jumper plane (°	90.0
	Current velocity (m/s)	0.4
Contents	Content density (kg/m3)	1025.0
Torsion ?		VRAI

Pup piece (mm)	10
Loop1 straight length (mm)	979.09
Loop2 straight length (mm)	979.09
Height straight length (mm)	5787.09
Middle straight length (mm)	17842.09
End 1 to conn. Straight (mm)	4983.5
End 2 to conn. Straight (mm)	4559.5
Conn (mm)	297
g (N/kg)	9.81
Bend radius (mm)	1095.5
Other	1106.5
Start line	3
End line	433

26439

Node 1	12
Force 1 (kN)	0
Node 2	02
Force 2 (kN)	0
Node 3	54
Force 3 (kN)	0

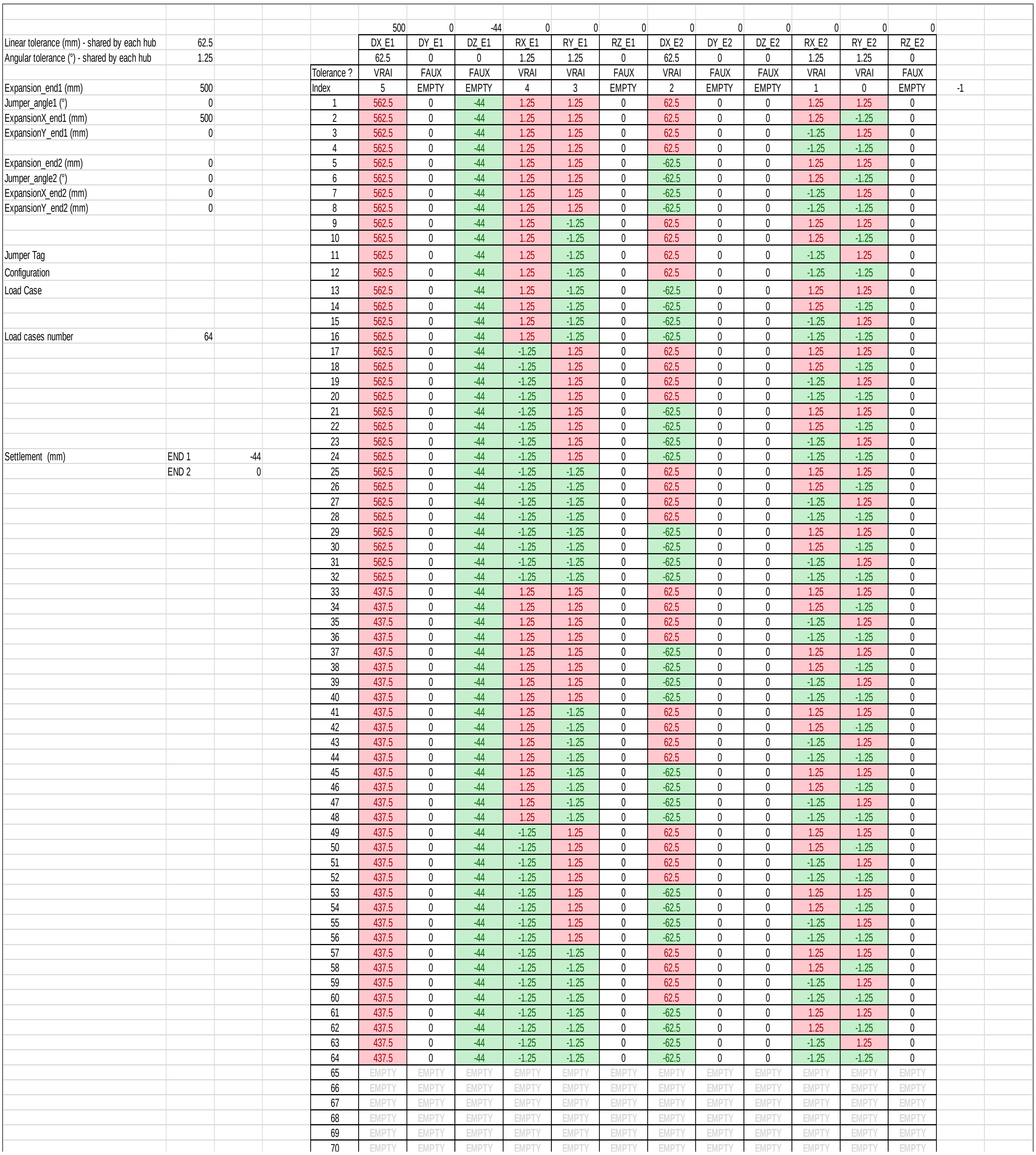
OD
ID
ID with CLAD

```
JOB      ED                                               1.7  09.04.01.05
    *
HED  BONGASW
CTL  031.8      Z   100        006.00   SI        SI        AUTOPIPE  AUTOB318
    *                    2010
DESC                                         ^n
    *       ^n                                        ^n
    *                ^n                                        ^n
    *                         ^n                                        ^n
    *                                  ^n
    * ^n                                        ^n  ^e
MINP N  N  Y  Y  Y  Y  Y  Y       N  Y  N  N  N  N  N  N  Y  N  N  N  N  N  Y  N  N  N  N
BUOY                 99000.000     1.027     1.000
PRIN                 Y  Y  Y  Y                        Y
***
SEG  A00                 0.000     0.000     0.000
PIPE PIPE1            -219.100    20.600     3.000    0.000
    *5LX-X65           322.675  .20427455             7833.028            .20427455
    *O               000.0000  000.0000  1.0250    00.000    0000.0000
    *                   1.0000    1.0000 .078567132  448.160
    *
    *
ANC          F  000000
DISP         T1          0562.500  0000.000 -0044.000  0001.250  0001.250  0000.000
DISP         T2          0562.500  0000.000 -0044.000  0001.250  0001.250  0000.000
DISP         T3          0562.500  0000.000 -0044.000  0001.250  0001.250  0000.000
DISP         T4          0562.500  0000.000 -0044.000  0001.250  0001.250  0000.000
DISP         T5          0562.500  0000.000 -0044.000  0001.250  0001.250  0000.000
DISP         T6          0562.500  0000.000 -0044.000  0001.250  0001.250  0000.000
DISP         T7          0562.500  0000.000 -0044.000  0001.250  0001.250  0000.000
DISP         T8          0562.500  0000.000 -0044.000  0001.250  0001.250  0000.000
DISP         T9          0562.500  0000.000 -0044.000  0001.250 -0001.250  0000.000
DISP        T10          0562.500  0000.000 -0044.000  0001.250 -0001.250  0000.000
DISP        T11          0562.500  0000.000 -0044.000  0001.250 -0001.250  0000.000
DISP        T12          0562.500  0000.000 -0044.000  0001.250 -0001.250  0000.000
DISP        T13          0562.500  0000.000 -0044.000  0001.250 -0001.250  0000.000
DISP        T14          0562.500  0000.000 -0044.000  0001.250 -0001.250  0000.000
DISP        T15          0562.500  0000.000 -0044.000  0001.250 -0001.250  0000.000
DISP        T16          0562.500  0000.000 -0044.000  0001.250 -0001.250  0000.000
DISP        T17          0562.500  0000.000 -0044.000 -0001.250  0001.250  0000.000
DISP        T18          0562.500  0000.000 -0044.000 -0001.250  0001.250  0000.000
DISP        T19          0562.500  0000.000 -0044.000 -0001.250  0001.250  0000.000
DISP        T20          0562.500  0000.000 -0044.000 -0001.250  0001.250  0000.000
DISP        T21          0562.500  0000.000 -0044.000 -0001.250  0001.250  0000.000
DISP        T22          0562.500  0000.000 -0044.000 -0001.250  0001.250  0000.000
DISP        T23          0562.500  0000.000 -0044.000 -0001.250  0001.250  0000.000
DISP        T24          0562.500  0000.000 -0044.000 -0001.250  0001.250  0000.000
DISP        T25          0562.500  0000.000 -0044.000 -0001.250 -0001.250  0000.000
DISP        T26          0562.500  0000.000 -0044.000 -0001.250 -0001.250  0000.000
DISP        T27          0562.500  0000.000 -0044.000 -0001.250 -0001.250  0000.000
DISP        T28          0562.500  0000.000 -0044.000 -0001.250 -0001.250  0000.000
DISP        T29          0562.500  0000.000 -0044.000 -0001.250 -0001.250  0000.000
DISP        T30          0562.500  0000.000 -0044.000 -0001.250 -0001.250  0000.000
DISP        T31          0562.500  0000.000 -0044.000 -0001.250 -0001.250  0000.000
DISP        T32          0562.500  0000.000 -0044.000 -0001.250 -0001.250  0000.000
DISP        T33          0437.500  0000.000 -0044.000  0001.250  0001.250  0000.000
DISP        T34          0437.500  0000.000 -0044.000  0001.250  0001.250  0000.000
DISP        T35          0437.500  0000.000 -0044.000  0001.250  0001.250  0000.000
DISP        T36          0437.500  0000.000 -0044.000  0001.250  0001.250  0000.000
DISP        T37          0437.500  0000.000 -0044.000  0001.250  0001.250  0000.000
DISP        T38          0437.500  0000.000 -0044.000  0001.250  0001.250  0000.000
DISP        T39          0437.500  0000.000 -0044.000  0001.250  0001.250  0000.000
DISP        T40          0437.500  0000.000 -0044.000  0001.250  0001.250  0000.000
DISP        T41          0437.500  0000.000 -0044.000  0001.250 -0001.250  0000.000
DISP        T42          0437.500  0000.000 -0044.000  0001.250 -0001.250  0000.000
DISP        T43          0437.500  0000.000 -0044.000  0001.250 -0001.250  0000.000
DISP        T44          0437.500  0000.000 -0044.000  0001.250 -0001.250  0000.000
DISP        T45          0437.500  0000.000 -0044.000  0001.250 -0001.250  0000.000
DISP        T46          0437.500  0000.000 -0044.000  0001.250 -0001.250  0000.000
DISP        T47          0437.500  0000.000 -0044.000  0001.250 -0001.250  0000.000
DISP        T48          0437.500  0000.000 -0044.000  0001.250 -0001.250  0000.000
DISP        T49          0437.500  0000.000 -0044.000 -0001.250  0001.250  0000.000
DISP        T50          0437.500  0000.000 -0044.000 -0001.250  0001.250  0000.000
DISP        T51          0437.500  0000.000 -0044.000 -0001.250  0001.250  0000.000
DISP        T52          0437.500  0000.000 -0044.000 -0001.250  0001.250  0000.000
DISP        T53          0437.500  0000.000 -0044.000 -0001.250  0001.250  0000.000
DISP        T54          0437.500  0000.000 -0044.000 -0001.250  0001.250  0000.000
DISP        T55          0437.500  0000.000 -0044.000 -0001.250  0001.250  0000.000
DISP        T56          0437.500  0000.000 -0044.000 -0001.250  0001.250  0000.000
DISP        T57          0437.500  0000.000 -0044.000 -0001.250 -0001.250  0000.000
DISP        T58          0437.500  0000.000 -0044.000 -0001.250 -0001.250  0000.000
DISP        T59          0437.500  0000.000 -0044.000 -0001.250 -0001.250  0000.000
DISP        T60          0437.500  0000.000 -0044.000 -0001.250 -0001.250  0000.000
DISP        T61          0437.500  0000.000 -0044.000 -0001.250 -0001.250  0000.000
DISP        T62          0437.500  0000.000 -0044.000 -0001.250 -0001.250  0000.000
DISP        T63          0437.500  0000.000 -0044.000 -0001.250 -0001.250  0000.000
DISP        T64          0437.500  0000.000 -0044.000 -0001.250 -0001.250  0000.000
OPER A00   1           6.000         034.000        A                A
    *             A
OPER A00   2           6.000         034.000        A                A
    *             A
OPER A00   3           6.000         034.000        A                A
    *             A
OPER A00   4           6.000         034.000        A                A
    *             A
OPER A00   5           6.000         034.000        A                A
    *             A
OPER A00   6           6.000         034.000        A                A
    *             A
OPER A00   7           6.000         034.000        A                A
    *             A
OPER A00   8           6.000         034.000        A                A
    *             A
OPER A00   9           6.000         034.000        A                A
    *             A
OPER A00  10           6.000         034.000        A                A
    *             A
OPER A00  11           6.000         034.000        A                A
    *             A
OPER A00  12           6.000         034.000        A                A
    *             A
OPER A00  13           6.000         034.000        A                A
    *             A
OPER A00  14           6.000         034.000        A                A
    *             A
OPER A00  15           6.000         034.000        A                A
    *             A
OPER A00  16           6.000         034.000        A                A
    *             A
OPER A00  17           6.000         034.000        A                A
    *             A
OPER A00  18           6.000         034.000        A                A
    *             A
OPER A00  19           6.000         034.000        A                A
    *             A
OPER A00  20           6.000         034.000        A                A
```

```
                        000.00
                                          PRIN          Y Y Y Y Y  N N N N Y Y N N N Y N N N N N
#NOM?           BUOY 1.C    1.000
                PIPE F-21   20.60C        3.000    0.000
                    *C00C   000.0C        1.0250   00.00C              0000.0000
            21  *O
            29  *O  000.0000
            31  *O  000.(
            39  *O  000.(   000.0000
            41  *O  000.(   000.0000
            47  *O  000.(   000.0000      1.0250
            51  *O  000.(   000.0000      1.0250
            57  *O  000.(   000.0000      1.0250   00.000
            61  *O  000.(   000.0000      1.0250   00.000
            70  *O  000.(   000.0000      1.0250   00.000              0000.0000
                OPER  A  00  1      6.000    034.0C        A       A   66
                   *          A
                OPER  A  00  2      6.000    034.0C        A       A   66
                   *          A
                OPER  A  00  3      6.000    034.0C        A       A   66
                   *          A
                OPER  A  00  4      6.000    034.0C        A       A   66
                   *          A
                OPER  A  00  5      6.000    034.0C        A       A   66
                   *          A
                OPER  A  00  6      6.000    034.0C        A       A   66
                   *          A
                OPER  A  00  7      6.000    034.0C        A       A   66
                   *          A
                OPER  A  00  8      6.000    034.0C        A       A   66
                   *          A
                OPER  A  00  9      6.000    034.0C        A       A   66
                   *          A
                OPER  A  00 10      6.000    034.0C        A       A   66
                   *          A
                OPER  A  00 11      6.000    034.0C        A       A   66
                   *          A
                OPER  A  00 12      6.000    034.0C        A       A   66
                   *          A
                OPER  A  00 13      6.000    034.0C        A       A   66
                   *          A
                OPER  A  00 14      6.000    034.0C        A       A   66
                   *          A
                OPER  A  00 15      6.000    034.0C        A       A   66
                   *          A
                OPER  A  00 16      6.000    034.0C        A       A   66
                   *          A
                OPER  A  00 17      6.000    034.0C        A       A   66
                   *          A
                OPER  A  00 18      6.000    034.0C        A       A   66
                   *          A
                OPER  A  00 19      6.000    034.0C        A       A   66
                   *          A
                OPER  A  00 20      6.000    034.0C        A       A   66
                   *          A
                OPER  A  00 21      6.000    034.0C        A       A   66
                   *          A
                OPER  A  00 22      6.000    034.0C        A       A   66
                   *          A
                OPER  A  00 23      6.000    034.0C        A       A   66
                   *          A
                OPER  A  00 24      6.000    034.0C        A       A   66
                   *          A
                OPER  A  00 25      6.000    034.0C        A       A   66
                   *          A
                OPER  A  00 26      6.000    034.0C        A       A   66
                   *          A
                OPER  A  00 27      6.000    034.0C        A       A   66
                   *          A
                OPER  A  00 28      6.000    034.0C        A       A   66
                   *          A
                OPER  A  00 29      6.000    034.0C        A       A   66
                   *          A
                OPER  A  00 30      6.000    034.0C        A       A   66
                   *          A
                OPER  A  00 31      6.000    034.0C        A       A   66
                   *          A
                OPER  A  00 32      6.000    034.0C        A       A   66
                   *          A
                OPER  A  00 33      6.000    034.0C        A       A   66
                   *          A
                OPER  A  00 34      6.000    034.0C        A       A   66
                   *          A
                OPER  A  00 35      6.000    034.0C        A       A   66
                   *          A
                OPER  A  00 36      6.000    034.0C        A       A   66
                   *          A
                OPER  A  00 37      6.000    034.0C        A       A   66
                   *          A
                OPER  A  00 38      6.000    034.0C        A       A   66
                   *          A
                OPER  A  00 39      6.000    034.0C        A       A   66
                   *          A
                OPER  A  00 40      6.000    034.0C        A       A   66
                   *          A
                OPER  A  00 41      6.000    034.0C        A       A   66
                   *          A
                OPER  A  00 42      6.000    034.0C        A       A   66
```

This excel worksheet is responsible of the generation of the Autopipe *.NTL file starting from the input variables. Nodes coordinates, Pressure and Temperature conditions as well as Load Cases configurations are created by this worksheet using excel functions.

4) “DISP” WORKSHEET



Linear tolerance (mm) - shared by each hub	62.5	
Angular tolerance (°) - shared by each hub	1.25	
Expansion_end1 (mm)	500	
Jumper_angle1 (°)	0	
ExpansionX_end1 (mm)	500	
ExpansionY_end1 (mm)	0	
Expansion_end2 (mm)	0	
Jumper_angle2 (°)	0	
ExpansionX_end2 (mm)	0	
ExpansionY_end2 (mm)	0	
Jumper Tag		
Configuration		
Load Case		
Load cases number	64	
Settlement (mm)	END 1	-44
	END 2	0

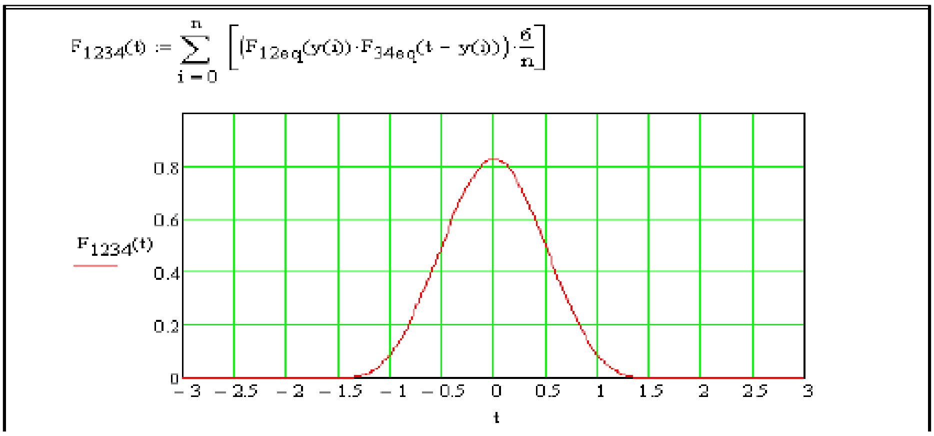
	500	0	-44	0	0	0	0	0	0	0	0	0	
	DX_E1	DY_E1	DZ_E1	RX_E1	RY_E1	RZ_E1	DX_E2	DY_E2	DZ_E2	RX_E2	RY_E2	RZ_E2	
	62.5	0	0	1.25	1.25	0	62.5	0	0	1.25	1.25	0	
Tolerance ?	VRAI	FAUX	FAUX	VRAI	VRAI	FAUX	VRAI	FAUX	FAUX	VRAI	VRAI	FAUX	
Index	5	EMPTY	EMPTY	4	3	EMPTY	2	EMPTY	EMPTY	1	0	EMPTY	-1
1	562.5	0	-44	1.25	1.25	0	62.5	0	0	1.25	1.25	0	
2	562.5	0	-44	1.25	1.25	0	62.5	0	0	1.25	-1.25	0	
3	562.5	0	-44	1.25	1.25	0	62.5	0	0	-1.25	1.25	0	
4	562.5	0	-44	1.25	1.25	0	62.5	0	0	-1.25	-1.25	0	
5	562.5	0	-44	1.25	1.25	0	-62.5	0	0	1.25	1.25	0	
6	562.5	0	-44	1.25	1.25	0	-62.5	0	0	1.25	-1.25	0	
7	562.5	0	-44	1.25	1.25	0	-62.5	0	0	-1.25	1.25	0	
8	562.5	0	-44	1.25	1.25	0	-62.5	0	0	-1.25	-1.25	0	
9	562.5	0	-44	1.25	-1.25	0	62.5	0	0	1.25	1.25	0	
10	562.5	0	-44	1.25	-1.25	0	62.5	0	0	1.25	-1.25	0	
11	562.5	0	-44	1.25	-1.25	0	62.5	0	0	-1.25	1.25	0	
12	562.5	0	-44	1.25	-1.25	0	62.5	0	0	-1.25	-1.25	0	
13	562.5	0	-44	1.25	-1.25	0	-62.5	0	0	1.25	1.25	0	
14	562.5	0	-44	1.25	-1.25	0	-62.5	0	0	1.25	-1.25	0	
15	562.5	0	-44	1.25	-1.25	0	-62.5	0	0	-1.25	1.25	0	
16	562.5	0	-44	1.25	-1.25	0	-62.5	0	0	-1.25	-1.25	0	
17	562.5	0	-44	-1.25	1.25	0	62.5	0	0	1.25	1.25	0	
18	562.5	0	-44	-1.25	1.25	0	62.5	0	0	1.25	-1.25	0	
19	562.5	0	-44	-1.25	1.25	0	62.5	0	0	-1.25	1.25	0	
20	562.5	0	-44	-1.25	1.25	0	62.5	0	0	-1.25	-1.25	0	
21	562.5	0	-44	-1.25	1.25	0	-62.5	0	0	1.25	1.25	0	
22	562.5	0	-44	-1.25	1.25	0	-62.5	0	0	1.25	-1.25	0	
23	562.5	0	-44	-1.25	1.25	0	-62.5	0	0	-1.25	1.25	0	
24	562.5	0	-44	-1.25	1.25	0	-62.5	0	0	-1.25	-1.25	0	
25	562.5	0	-44	-1.25	-1.25	0	62.5	0	0	1.25	1.25	0	
26	562.5	0	-44	-1.25	-1.25	0	62.5	0	0	1.25	-1.25	0	
27	562.5	0	-44	-1.25	-1.25	0	62.5	0	0	-1.25	1.25	0	
28	562.5	0	-44	-1.25	-1.25	0	62.5	0	0	-1.25	-1.25	0	
29	562.5	0	-44	-1.25	-1.25	0	-62.5	0	0	1.25	1.25	0	
30	562.5	0	-44	-1.25	-1.25	0	-62.5	0	0	1.25	-1.25	0	
31	562.5	0	-44	-1.25	-1.25	0	-62.5	0	0	-1.25	1.25	0	
32	562.5	0	-44	-1.25	-1.25	0	-62.5	0	0	-1.25	-1.25	0	
33	437.5	0	-44	1.25	1.25	0	62.5	0	0	1.25	1.25	0	
34	437.5	0	-44	1.25	1.25	0	62.5	0	0	1.25	-1.25	0	
35	437.5	0	-44	1.25	1.25	0	62.5	0	0	-1.25	1.25	0	
36	437.5	0	-44	1.25	1.25	0	62.5	0	0	-1.25	-1.25	0	
37	437.5	0	-44	1.25	1.25	0	-62.5	0	0	1.25	1.25	0	
38	437.5	0	-44	1.25	1.25	0	-62.5	0	0	1.25	-1.25	0	
39	437.5	0	-44	1.25	1.25	0	-62.5	0	0	-1.25	1.25	0	
40	437.5	0	-44	1.25	1.25	0	-62.5	0	0	-1.25	-1.25	0	
41	437.5	0	-44	1.25	-1.25	0	62.5	0	0	1.25	1.25	0	
42	437.5	0	-44	1.25	-1.25	0	62.5	0	0	1.25	-1.25	0	
43	437.5	0	-44	1.25	-1.25	0	62.5	0	0	-1.25	1.25	0	
44	437.5	0	-44	1.25	-1.25	0	62.5	0	0	-1.25	-1.25	0	
45	437.5	0	-44	1.25	-1.25	0	-62.5	0	0	1.25	1.25	0	
46	437.5	0	-44	1.25	-1.25	0	-62.5	0	0	1.25	-1.25	0	
47	437.5	0	-44	1.25	-1.25	0	-62.5	0	0	-1.25	1.25	0	
48	437.5	0	-44	1.25	-1.25	0	-62.5	0	0	-1.25	-1.25	0	
49	437.5	0	-44	-1.25	1.25	0	62.5	0	0	1.25	1.25	0	
50	437.5	0	-44	-1.25	1.25	0	62.5	0	0	1.25	-1.25	0	
51	437.5	0	-44	-1.25	1.25	0	62.5	0	0	-1.25	1.25	0	
52	437.5	0	-44	-1.25	1.25	0	62.5	0	0	-1.25	-1.25	0	
53	437.5	0	-44	-1.25	1.25	0	-62.5	0	0	1.25	1.25	0	
54	437.5	0	-44	-1.25	1.25	0	-62.5	0	0	1.25	-1.25	0	
55	437.5	0	-44	-1.25	1.25	0	-62.5	0	0	-1.25	1.25	0	
56	437.5	0	-44	-1.25	1.25	0	-62.5	0	0	-1.25	-1.25	0	
57	437.5	0	-44	-1.25	-1.25	0	62.5	0	0	1.25	1.25	0	
58	437.5	0	-44	-1.25	-1.25	0	62.5	0	0	1.25	-1.25	0	
59	437.5	0	-44	-1.25	-1.25	0	62.5	0	0	-1.25	1.25	0	
60	437.5	0	-44	-1.25	-1.25	0	62.5	0	0	-1.25	-1.25	0	
61	437.5	0	-44	-1.25	-1.25	0	-62.5	0	0	1.25	1.25	0	
62	437.5	0	-44	-1.25	-1.25	0	-62.5	0	0	1.25	-1.25	0	
63	437.5	0	-44	-1.25	-1.25	0	-62.5	0	0	-1.25	1.25	0	
64	437.5	0	-44	-1.25	-1.25	0	-62.5	0	0	-1.25	-1.25	0	
65	EMPTY	EMPTY	EMPTY	EMPTY	EMPTY	EMPTY	EMPTY	EMPTY	EMPTY	EMPTY	EMPTY	EMPTY	
66	EMPTY	EMPTY	EMPTY	EMPTY	EMPTY	EMPTY	EMPTY	EMPTY	EMPTY	EMPTY	EMPTY	EMPTY	
67	EMPTY	EMPTY	EMPTY	EMPTY	EMPTY	EMPTY	EMPTY	EMPTY	EMPTY	EMPTY	EMPTY	EMPTY	
68	EMPTY	EMPTY	EMPTY	EMPTY	EMPTY	EMPTY	EMPTY	EMPTY	EMPTY	EMPTY	EMPTY	EMPTY	
69	EMPTY	EMPTY	EMPTY	EMPTY	EMPTY	EMPTY	EMPTY	EMPTY	EMPTY	EMPTY	EMPTY	EMPTY	
70	EMPTY	EMPTY	EMPTY	EMPTY	EMPTY	EMPTY	EMPTY	EMPTY	EMPTY	EMPTY	EMPTY	EMPTY	

The displacement matrix is built automatically taking into consideration :

- The linear installation and metrology tolerances along X and Y.
- The Angular installation and metrology tolerances.
- The expansions of the line at both extremities of the Jumpers with their projection on the X,Y axis according to angle layout.
- The settlement of each extremities.

The tolerances can be positively applied or negatively. Consequently the total number of imposed

displacement cases is composed of : 2^6=64 cases.
Combining all the extreme tolerances could result in very conservative stress and interface loads. Therefore a probability approach is sometimes used., assuming that all the individual tolerances follow a uniform distribution within the tolerance limit. The cumulative probability for the total tolerance can then be defined, as shown in Figure 47



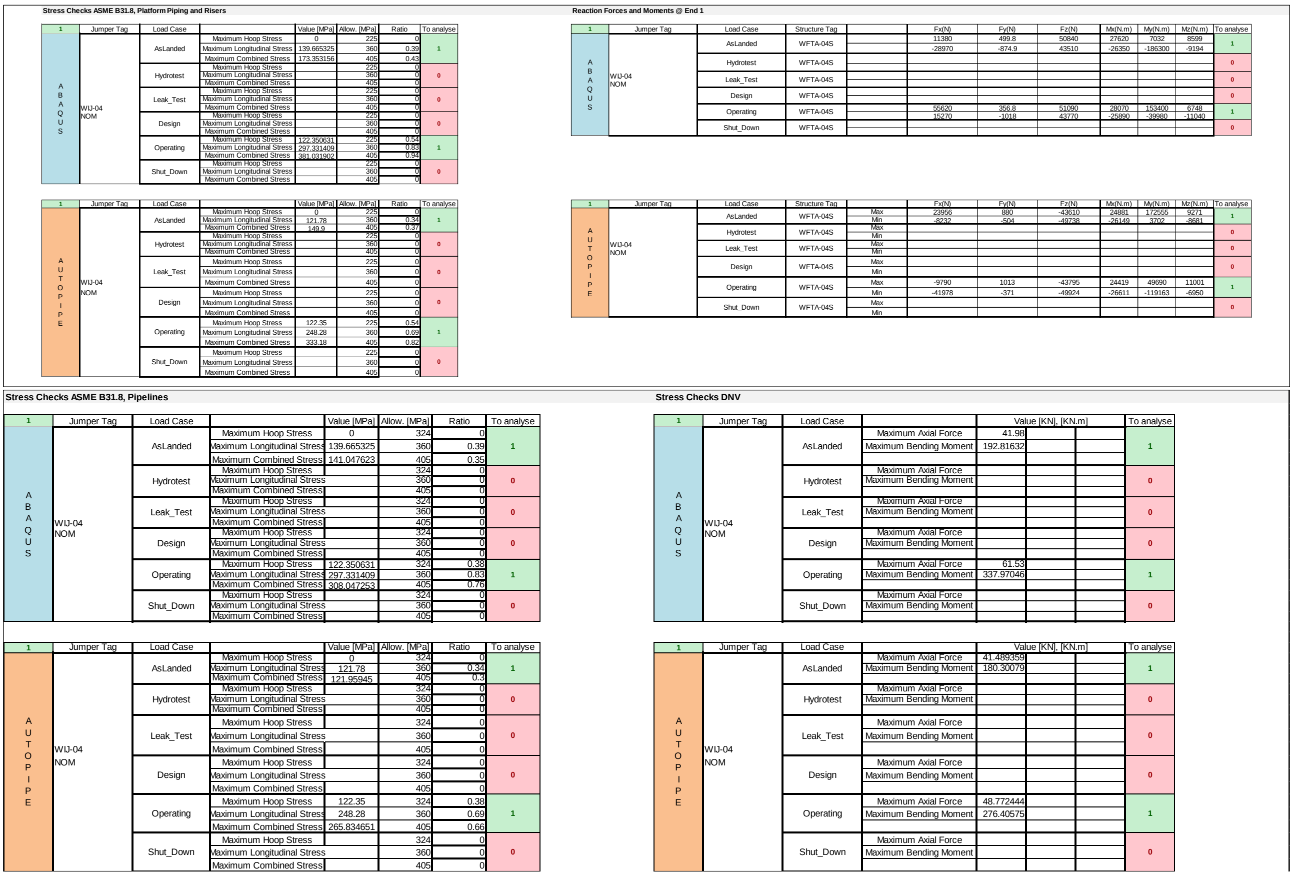
$$F_{1234}(t) := \sum_{i=0}^{n} \left[\left(F_{12eq}(y(i)) \cdot F_{34eq}(t - y(i)) \right) \cdot \frac{6}{n} \right]$$

Figure 47. Typical Cumulative Probability

As for the current thesis project, all the tolerances are conserved for testing in order to have a general design tool.

In order to analyse each metrological configuration accurately, single Abaqus script files have been written including only one displacement load case. Indeed the plastic behaviour of the structure should not be reached to take correctly into account the load case.

5) “RESULTS” WORKSHEET



Stress Checks ASME B31.8, Platform Piping and Risers

1	Jumper Tag	Load Case		Value [MPa]	Allow. [MPa]	Ratio	To analyse
ABAQUS	WIJ-04 NOM	AsLanded	Maximum Hoop Stress	0	225	0	1
			Maximum Longitudinal Stress	139.665325	360	0.39	
			Maximum Combined Stress	173.353156	405	0.43	
		Hydrotest	Maximum Hoop Stress		225	0	0
			Maximum Longitudinal Stress		360	0	
			Maximum Combined Stress		405	0	
		Leak_Test	Maximum Hoop Stress		225	0	0
			Maximum Longitudinal Stress		360	0	
			Maximum Combined Stress		405	0	
		Design	Maximum Hoop Stress		225	0	0
			Maximum Longitudinal Stress		360	0	
			Maximum Combined Stress		405	0	
		Operating	Maximum Hoop Stress	122.350631	225	0.54	1
			Maximum Longitudinal Stress	297.331409	360	0.83	
			Maximum Combined Stress	381.031902	405	0.94	
		Shut_Down	Maximum Hoop Stress		225	0	0
			Maximum Longitudinal Stress		360	0	
			Maximum Combined Stress		405	0	

1	Jumper Tag	Load Case		Value [MPa]	Allow. [MPa]	Ratio	To analyse
AUTOPIPE	WIJ-04 NOM	AsLanded	Maximum Hoop Stress	0	225	0	1
			Maximum Longitudinal Stress	121.78	360	0.34	
			Maximum Combined Stress	149.9	405	0.37	
		Hydrotest	Maximum Hoop Stress		225	0	0
			Maximum Longitudinal Stress		360	0	
			Maximum Combined Stress		405	0	
		Leak_Test	Maximum Hoop Stress		225	0	0
			Maximum Longitudinal Stress		360	0	
			Maximum Combined Stress		405	0	
		Design	Maximum Hoop Stress		225	0	0
			Maximum Longitudinal Stress		360	0	
			Maximum Combined Stress		405	0	
		Operating	Maximum Hoop Stress	122.35	225	0.54	1
			Maximum Longitudinal Stress	248.28	360	0.69	
			Maximum Combined Stress	333.18	405	0.82	
		Shut_Down	Maximum Hoop Stress		225	0	0
			Maximum Longitudinal Stress		360	0	
			Maximum Combined Stress		405	0	

Reaction Forces and Moments @ End 1

1	Jumper Tag	Load Case	Structure Tag		Fx(N)	Fy(N)	Fz(N)	Mx(N.m)	My(N.m)	Mz(N.m)	To analyse
ABAQUS	WIJ-04 NOM	AsLanded	WFTA-04S		11380	499.8	50840	27620	7032	8599	1
					-28970	-874.9	43510	-26350	-186300	-9194	
		Hydrotest	WFTA-04S								0
		Leak_Test	WFTA-04S								0
		Design	WFTA-04S								0
		Operating	WFTA-04S		55620	356.8	51090	28070	153400	6748	1
					15270	-1018	43770	-25890	-39980	-11040	
		Shut_Down	WFTA-04S								0

1	Jumper Tag	Load Case	Structure Tag		Fx(N)	Fy(N)	Fz(N)	Mx(N.m)	My(N.m)	Mz(N.m)	To analyse
AUTOPIPE	WIJ-04 NOM	AsLanded	WFTA-04S	Max	23956	880	-43610	24881	172555	9271	1
				Min	-8232	-504	-49738	-26149	3702	-8681	
		Hydrotest	WFTA-04S	Max							0
				Min							
		Leak_Test	WFTA-04S	Max							0
				Min							
		Design	WFTA-04S	Max							0
				Min							
		Operating	WFTA-04S	Max	-9790	1013	-43795	24419	49690	11001	1
				Min	-41978	-371	-49924	-26611	-119163	-6950	
		Shut_Down	WFTA-04S	Max							0
				Min							

Stress Checks ASME B31.8, Pipelines

1	Jumper Tag	Load Case		Value [MPa]	Allow. [MPa]	Ratio	To analyse
ABAQUS	WIJ-04 NOM	AsLanded	Maximum Hoop Stress	0	324	0	1
			Maximum Longitudinal Stress	139.665325	360	0.39	
			Maximum Combined Stress	141.047623	405	0.35	
		Hydrotest	Maximum Hoop Stress		324	0	0
			Maximum Longitudinal Stress		360	0	
			Maximum Combined Stress		405	0	
		Leak_Test	Maximum Hoop Stress		324	0	0
			Maximum Longitudinal Stress		360	0	
			Maximum Combined Stress		405	0	
		Design	Maximum Hoop Stress		324	0	0
			Maximum Longitudinal Stress		360	0	
			Maximum Combined Stress		405	0	
		Operating	Maximum Hoop Stress	122.350631	324	0.38	1
			Maximum Longitudinal Stress	297.331409	360	0.83	
			Maximum Combined Stress	308.047253	405	0.76	
		Shut_Down	Maximum Hoop Stress		324	0	0
			Maximum Longitudinal Stress		360	0	
			Maximum Combined Stress		405	0	

1	Jumper Tag	Load Case		Value [MPa]	Allow. [MPa]	Ratio	To analyse
AUTOPIPE	WIJ-04 NOM	AsLanded	Maximum Hoop Stress	0	324	0	1
			Maximum Longitudinal Stress	121.78	360	0.34	
			Maximum Combined Stress	121.95945	405	0.3	
		Hydrotest	Maximum Hoop Stress		324	0	0
			Maximum Longitudinal Stress		360	0	
			Maximum Combined Stress		405	0	
		Leak_Test	Maximum Hoop Stress		324	0	0
			Maximum Longitudinal Stress		360	0	
			Maximum Combined Stress		405	0	
		Design	Maximum Hoop Stress		324	0	0
			Maximum Longitudinal Stress		360	0	
			Maximum Combined Stress		405	0	
		Operating	Maximum Hoop Stress	122.35	324	0.38	1
			Maximum Longitudinal Stress	248.28	360	0.69	
			Maximum Combined Stress	265.834651	405	0.66	
		Shut_Down	Maximum Hoop Stress		324	0	0
			Maximum Longitudinal Stress		360	0	
			Maximum Combined Stress		405	0	

Stress Checks DNV

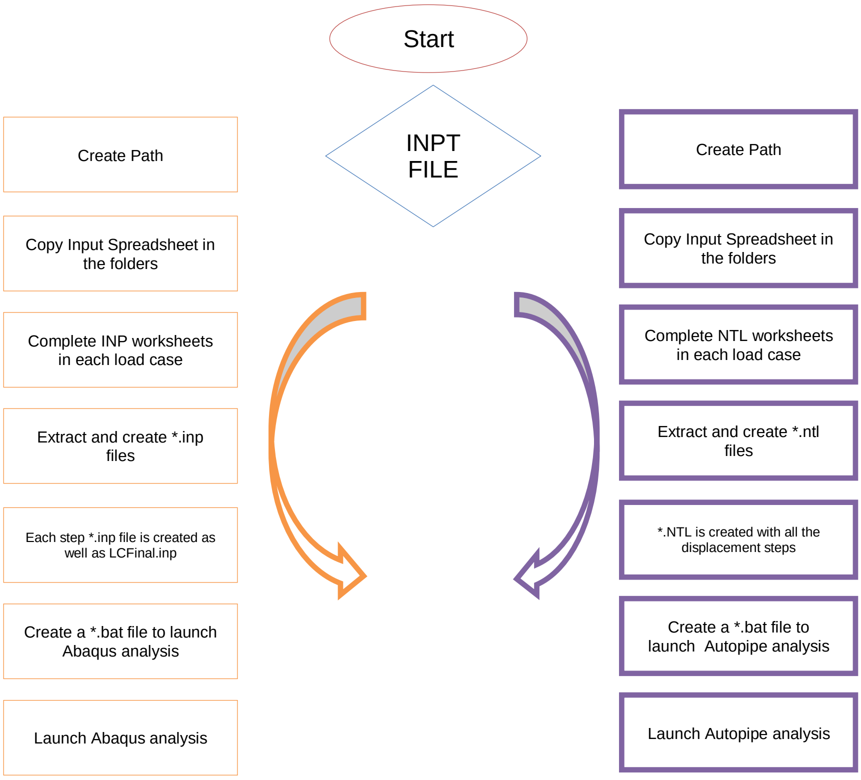
1	Jumper Tag	Load Case		Value [KN], [KN.m]			To analyse
ABAQUS	WIJ-04 NOM	AsLanded	Maximum Axial Force	41.98			1
			Maximum Bending Moment	192.81632			
		Hydrotest	Maximum Axial Force				0
			Maximum Bending Moment				
		Leak_Test	Maximum Axial Force				0
			Maximum Bending Moment				
		Design	Maximum Axial Force				0
			Maximum Bending Moment				
		Operating	Maximum Axial Force	61.53			1
			Maximum Bending Moment	337.97046			
		Shut_Down	Maximum Axial Force				0
			Maximum Bending Moment				

1	Jumper Tag	Load Case		Value [KN], [KN.m]			To analyse
AUTOPIPE	WIJ-04 NOM	AsLanded	Maximum Axial Force	41.489359			1
			Maximum Bending Moment	180.30079			
		Hydrotest	Maximum Axial Force				0
			Maximum Bending Moment				
		Leak_Test	Maximum Axial Force				0
			Maximum Bending Moment				
		Design	Maximum Axial Force				0
			Maximum Bending Moment				
		Operating	Maximum Axial Force	48.772444			1
			Maximum Bending Moment	276.40575			
		Shut_Down	Maximum Axial Force				0
			Maximum Bending Moment				

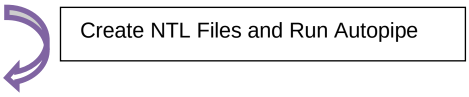
The “RESULTS” worksheet summarizes the stresses of ASME B31.8 and reaction loads at both extremities. The DNV checks are also performed in the same worksheet. All the load cases (As Landed, Hydrotest, Leak Test, Design, Operating and Shut Down) are completed into tables. Comparison between ABAQUS and AUTOPIPE can be done.

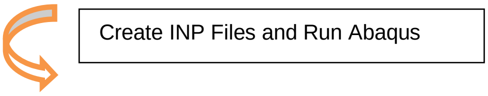
4.2.1 Process Flowchart

The input spreadsheet is based on a VBA code that is taking the input variable and transferring their values into the two excel worksheets INP and NTL. Those worksheets have been developed so that each line of the Abaqus and Autopipe codes are parameterized by input variables. An extracting code is generating the *.INP and *.NTL files.



Each of the directional arrow represents an excel button available to the user.





4.2.2 Launching and Results

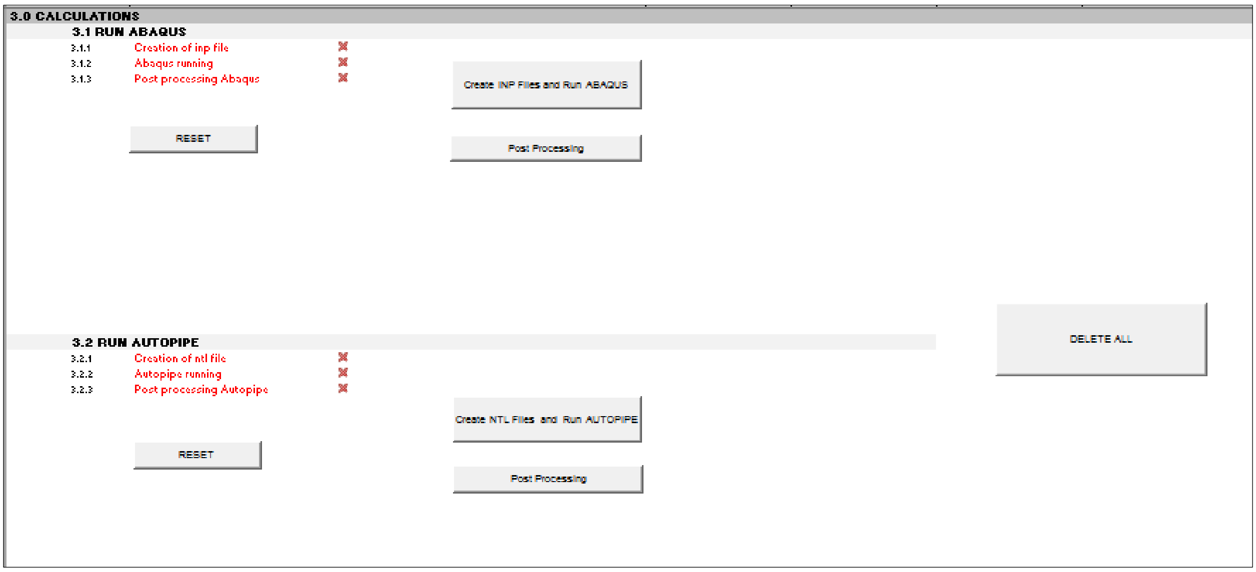
The input spreadsheet creates a temp_abaqus.bat and a temp_autopipe.bat file. Those files enable the launching of the Abaqus and Autopipe scripts.
In order to launch Abaqus analysis, the following line should be written:

```
Cd        C:\directory
call abaqus input=NameofFile job=NameofFile cpus=7 int
```

In order to launch Autopipe analysis, the following line should be written:

```
Cd        C:\Autopipe_directory
Autopipe C:\directory\filename.ntl /s /b /p
```

User can observe progress in the input processing and post processing actions thanks to the green and red check crosses. Moreover loading bar with percentage of completion of the task are printed on the screen when using the spreadsheet functions.



3.0 CALCULATIONS

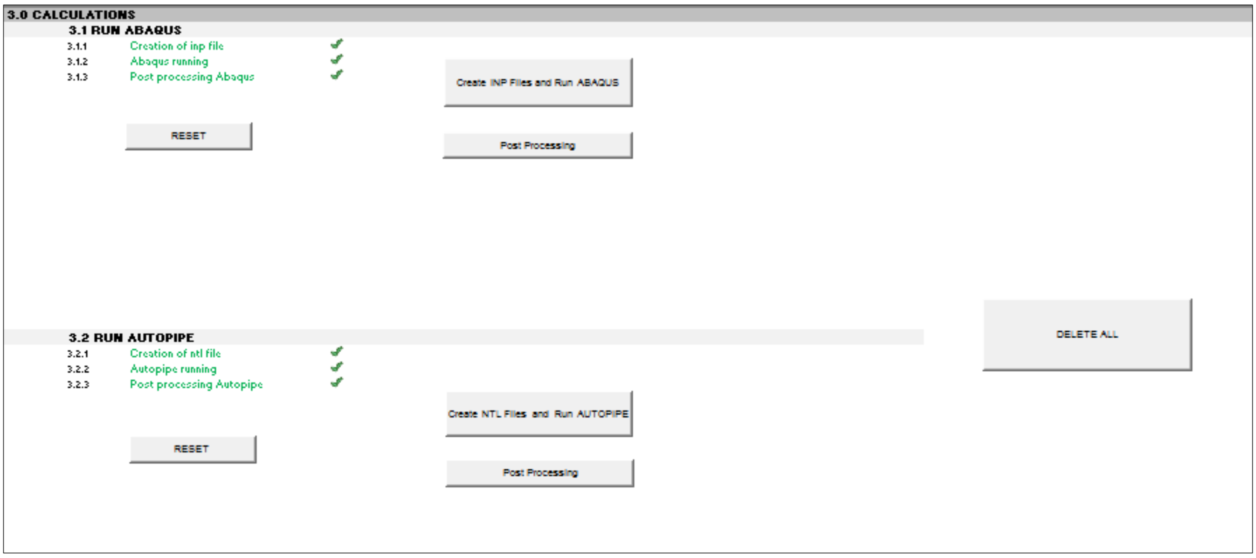
3.1 RUN ABAQUS

3.1.1 Creation of inp file ✗
3.1.2 Abaqus running ✗
3.1.3 Post processing Abaqus ✗

3.2 RUN AUTOPIPE

3.2.1 Creation of ntl file ✗
3.2.2 Autopipe running ✗
3.2.3 Post processing Autopipe ✗

Figure 48. Screenshot worksheet "INPUT" 3.0 CALCULATION part before loading data



3.0 CALCULATIONS

3.1 RUN ABAQUS

3.1.1 Creation of inp file ✓
3.1.2 Abaqus running ✓
3.1.3 Post processing Abaqus ✓

3.2 RUN AUTOPIPE

3.2.1 Creation of ntl file ✓
3.2.2 Autopipe running ✓
3.2.3 Post processing Autopipe ✓

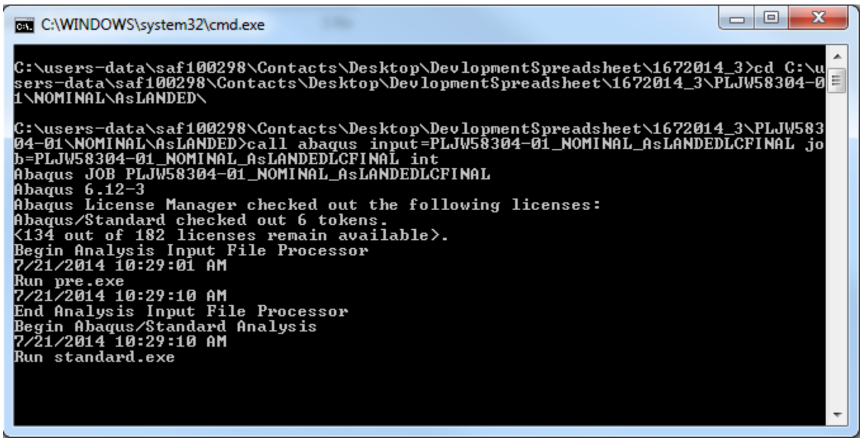
Figure 49. Screenshot worksheet "INPUT" 3.0 CALCULATION part after loading data

Once the analysis is completed, a *.OUT file is created by Autopipe and a *.DAT file is generated by Abaqus. It is then possible to collect the displacements, the reaction forces and moments and the sectional forces and moments. An extracting VBA code has been developed to ease the operation of importing automatically the results of the analysis into excel worksheets.

The post processing is done thanks to the import data options of excel. Indeed starting from the FEA program outputs, a VBA code create text files that can easily be imported into excel. Then the post processing VBA code (see Attachement C) orders the data of each variable (displacement along X, Sectional Force Y…) into tables in order to compute the maximum values. Additionally mathematical operations are carried on, to obtain the ASME and DNV code checks. Those operations have been described in 3.1.2, their practical applications will be details in the part 3.3 of this report.

4.2.3 Abaqus Files

When the run of the solver begins, i.e., the sentence “Run standard.exe” appears on the command window, Abaqus analysis starts. At the same time, in the folder where all the input files are saved, the following new files are created:



```
C:\users-data\saf100298\Contacts\Desktop\DevlopmentSpreadsheet\1672014_3>cd C:\u
sers-data\saf100298\Contacts\Desktop\DevlopmentSpreadsheet\1672014_3\PLJW58304-0
1\NOMINAL\AsLANDED\

C:\users-data\saf100298\Contacts\Desktop\DevlopmentSpreadsheet\1672014_3\PLJW583
04-01\NOMINAL\AsLANDED>call abaqus input=PLJW58304-01_NOMINAL_AsLANDEDLCFINAL jo
b=PLJW58304-01_NOMINAL_AsLANDEDLCFINAL int
Abaqus JOB PLJW58304-01_NOMINAL_AsLANDEDLCFINAL
Abaqus 6.12-3
Abaqus License Manager checked out the following licenses:
Abaqus/Standard checked out 6 tokens.
<134 out of 182 licenses remain available>.
Begin Analysis Input File Processor
7/21/2014 10:29:01 AM
Run pre.exe
7/21/2014 10:29:10 AM
End Analysis Input File Processor
Begin Abaqus/Standard Analysis
7/21/2014 10:29:10 AM
Run standard.exe
```

Figure 50. Screenshot Abaqus command windows, the solver begins to run

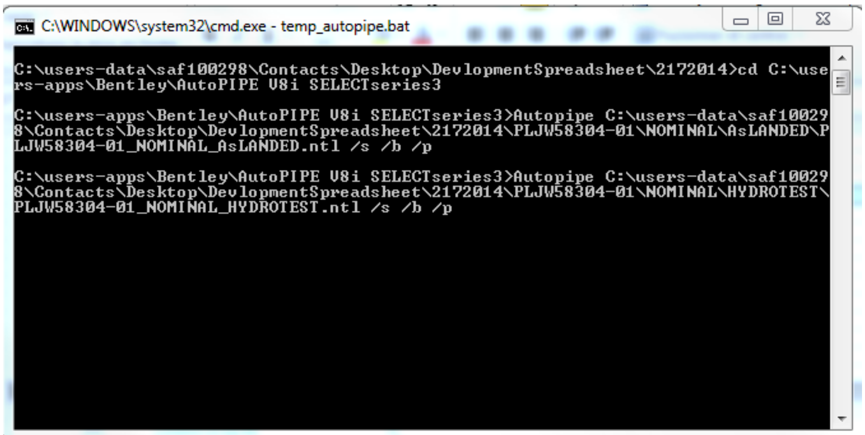
NameJumper_Config_loadcaseLCFinal.com	Command file, created by the Abaqus execution procedure
NameJumper_Config_loadcaseLCFinal.dat	Printed output file. It is written by the analysis, data check and parameter check option.
NameJumper_Config_loadcaseLCFinal.lck	Lock file for the output database. This file is written whenever an output database file is opened with write access; it prevents you from having simultaneous write permission to the output database from multiple sources. It is deleted automatically when the output database file is closed or when the analysis that creates it ends.
NameJumper_Config_loadcaseLCFinal.msg	Message file.
NameJumper_Config_loadcaseLCFinal.odb	Output database. It is written by the analysis and continue options in Abaqus/Standard and Abaqus/Explicit. It is read by the Visualization module in Abaqus/CAE (Abaqus/Viewer) and by the convert=odb option. This file is required for restart.
NameJumper_Config_loadcaseLCFinal.par	Modified version of original parameterized input file showing input parameters and their values.
NameJumper_Config_loadcaseLCFinal.pes	Modified version of original parameterized input file showing input free of parameter information (after input parameter evaluation and substitution has been performed).
NameJumper_Config_loadcaseLCFinal.pmg	Parameter evaluation and substitution message file. It is written when the input file is parameterized.
NameJumper_Config_loadcaseLCFinal.prt	Part file, used by Abaqus/Standard and Abaqus/Explicit. This file is used to store part and assembly information and is created even if the input file does not contain an assembly definition. The part file is required for restart, import, sequentially coupled thermal-stress analysis, symmetric model generation, and underwater shock analysis, even if the model is not defined in terms of an assembly of part instances. This file may also be needed for sub-modelling

	analysis.
NameJumper_Config_loadcaseLCFinal.sim	Linear dynamics data file, used by Abaqus/Standard. It is written during the frequency extraction procedure in SIM-based linear dynamics analyses and is used to store eigenvectors, substructure matrices, and other modal system information. This file is required for restart. Model file, used by Abaqus/CFD. It is written by the data check option. It is read and can be written by the analysis and continue options. This file is required for restart.
NameJumper_Config_loadcaseLCFinal.sta	Status file. Abaqus writes increment summaries to this file in the analysis, continue, and recover options.

The post processing code will extract relevant data from the *.DAT file.

4.2.4 Autopipe Files

When the run of the solver begins, Autopipe analysis starts. At the same time, in the folder where all the input files are saved, the following new files are created :



```
C:\users-data\saf100298\Contacts\Desktop\DevlopmentSpreadsheet\2172014>cd C:\use
rs-apps\Bentley\AutoPIPE V8i SELECTseries3

C:\users-apps\Bentley\AutoPIPE V8i SELECTseries3>Autopipe C:\users-data\saf10029
8\Contacts\Desktop\DevlopmentSpreadsheet\2172014\PLJW58304-01\NOMINAL\AsLANDED\P
LJW58304-01_NOMINAL_AsLANDED.ntl /s /b /p

C:\users-apps\Bentley\AutoPIPE V8i SELECTseries3>Autopipe C:\users-data\saf10029
8\Contacts\Desktop\DevlopmentSpreadsheet\2172014\PLJW58304-01\NOMINAL\HYDROTEST\
PLJW58304-01_NOMINAL_HYDROTEST.ntl /s /b /p
```

Figure 51. Screenshot Autopipe command windows, the solver begins to run

NameJumper_Config_loadcaseLCFinal.OUT	The Result Output Report which contains the outputs data.
NameJumper_Config_loadcaseLCFinal.dat	The Model File that could be open with AUTOPIPE software to verify the geometry.
NameJumper_Config_loadcaseLCFinal.MSG	The Message File which contains the possible warnings and errors of the analysis.
NameJumper_Config_loadcaseLCFinal.LOG	This file can be used to identify the support(s) which failed to converge.
NameJumper_Config_loadcaseLCFinal.CMB	This is the model combination file.
NameJumper_Config_loadcaseLCFinal.CHK	This is the Model Consistency Check.

The post processing code will extract relevant data from the *.OUT file.

4.3 POST PROCESSING SPREADSHEETS

The purpose of those spreadsheets (FORM-SSA-SFD-FLOWS-055-E & FORM-SSA-SFD-FLOWS-056-E) is:

- To load the output data of Abaqus and Autopipe analysis.
- To calculate mechanical parameters of the Jumper (section modulus, areas, end cap effects)
- To compute the Stresses required by the standards and isolate the maximum values.

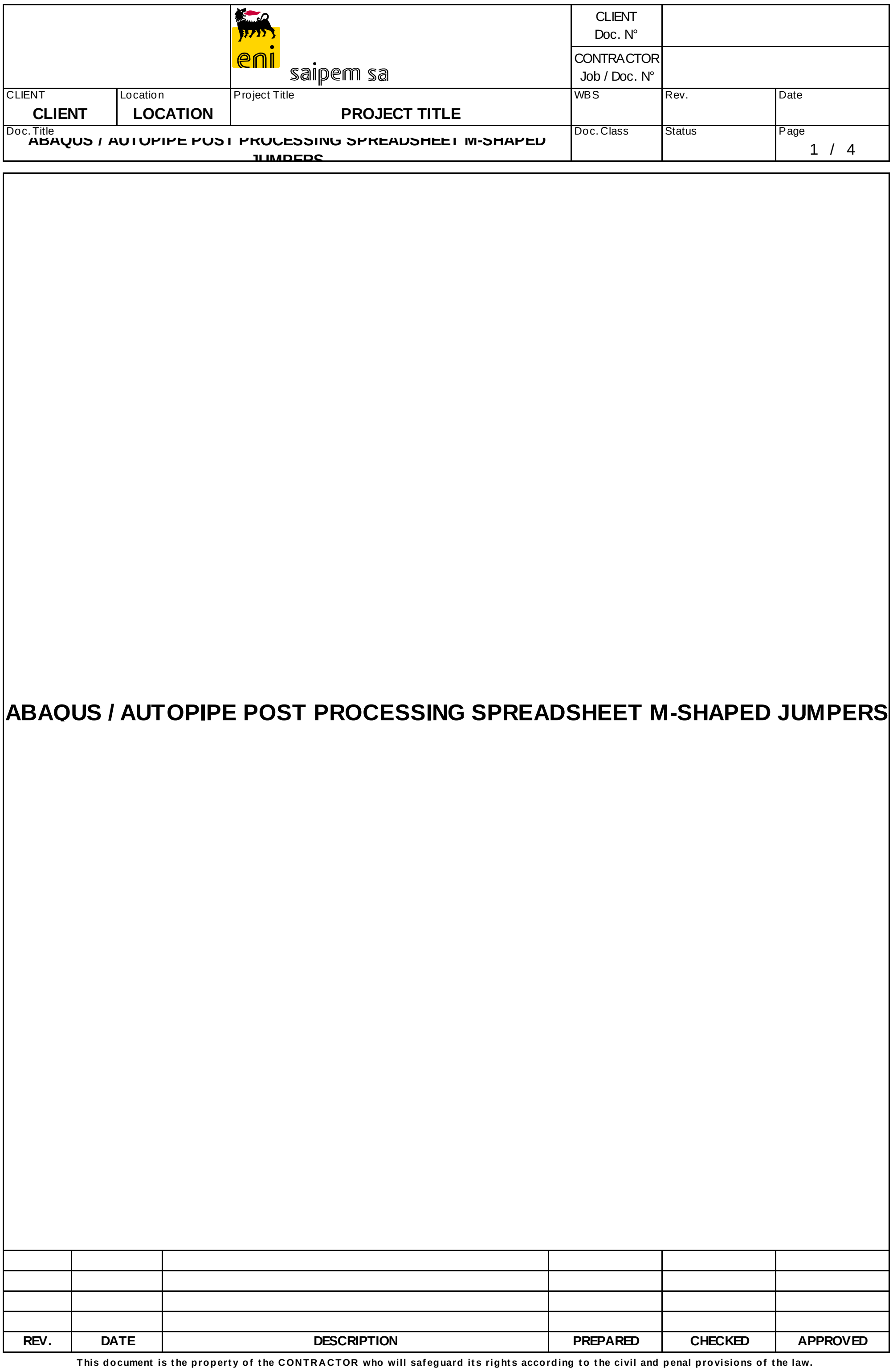
- To draw out the graphs of the displacements, forces, moments, stresses along the Jumper

VBA code has been used to automatize the post processing starting from the *.DAT and *.OUT files respectively from Abaqus and Autopipe. (see Attachement D). For each Jumper and each configuration a different spreadsheet will be completed.

Standard quality requirements of the Flowline Department of Saipem have been respected. The spreadsheet is composed of 9 main worksheets:

COVER PAGE, REVISION HISTORY, OUTPUTS, INPUTS, GRAPHS, DISPLACEMENTS, REACTIONS, FORCES&MOMENTS, STRESSES

1) “COVER PAGE” WORKSHEET



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			CONTRACTOR Job / Doc. N°		
CLIENT **CLIENT**	Location **LOCATION**	Project Title **PROJECT TITLE**	WBS	Rev.	Date
Doc. Title **ABAQUS / AUTOPIPE POST PROCESSING SPREADSHEET M-SHAPED JUMPERS**			Doc. Class	Status	Page 1 / 4

ABAQUS / AUTOPIPE POST PROCESSING SPREADSHEET M-SHAPED JUMPERS

REV.	**DATE**	**DESCRIPTION**	**PREPARED**	**CHECKED**	**APPROVED**

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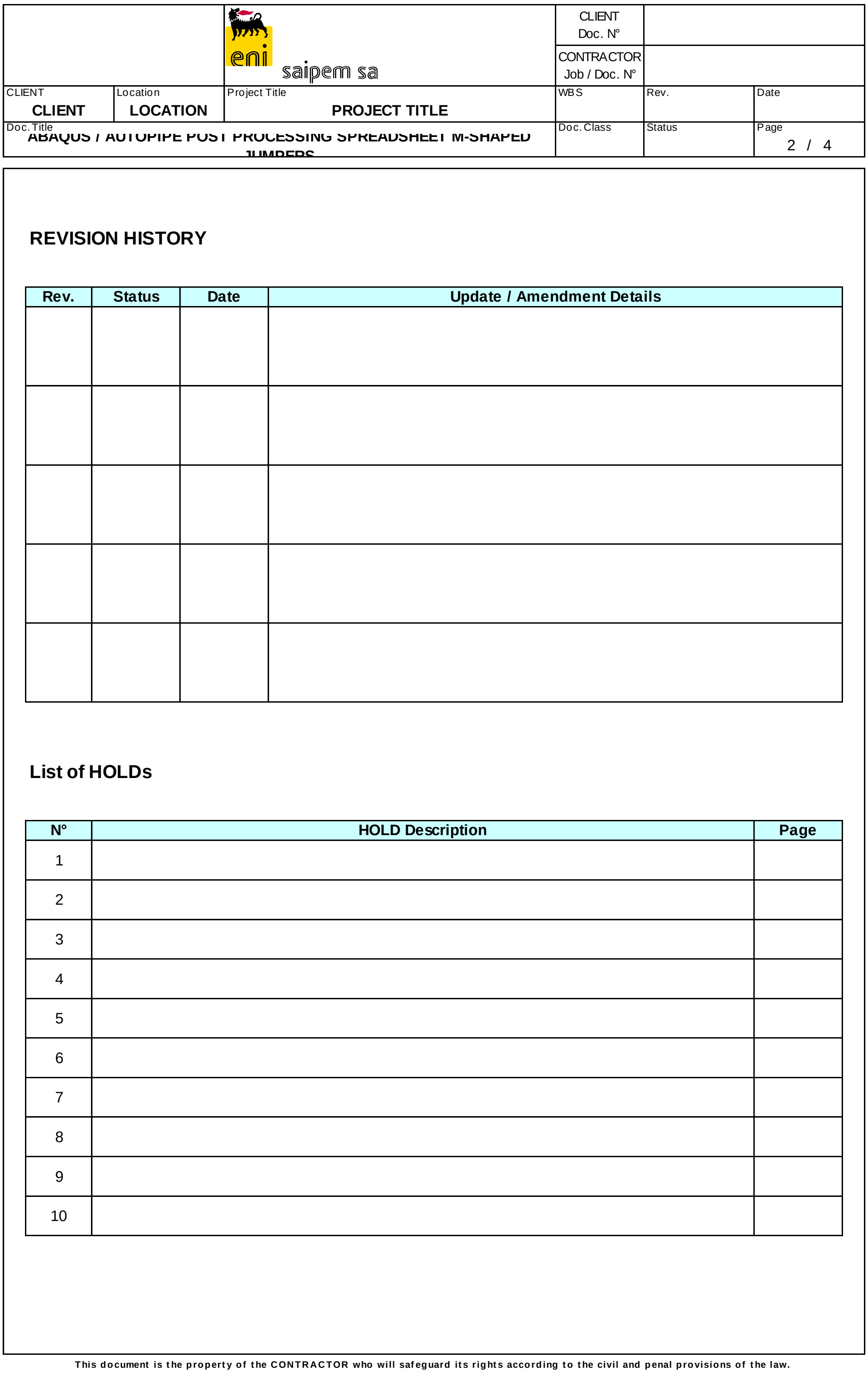
2) “REVISION HISTORY” WORKSHEET



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			CONTRACTOR Job / Doc. N°		
CLIENT **CLIENT**	Location **LOCATION**	Project Title **PROJECT TITLE**	WBS	Rev.	Date
Doc. Title **ABAQUS / AUTOPIPE POST PROCESSING SPREADSHEET M-SHAPED JUMPERS**			Doc. Class	Status	Page 2 / 4

REVISION HISTORY

Rev.	Status	Date	Update / Amendment Details

List of HOLDs

N°	HOLD Description	Page
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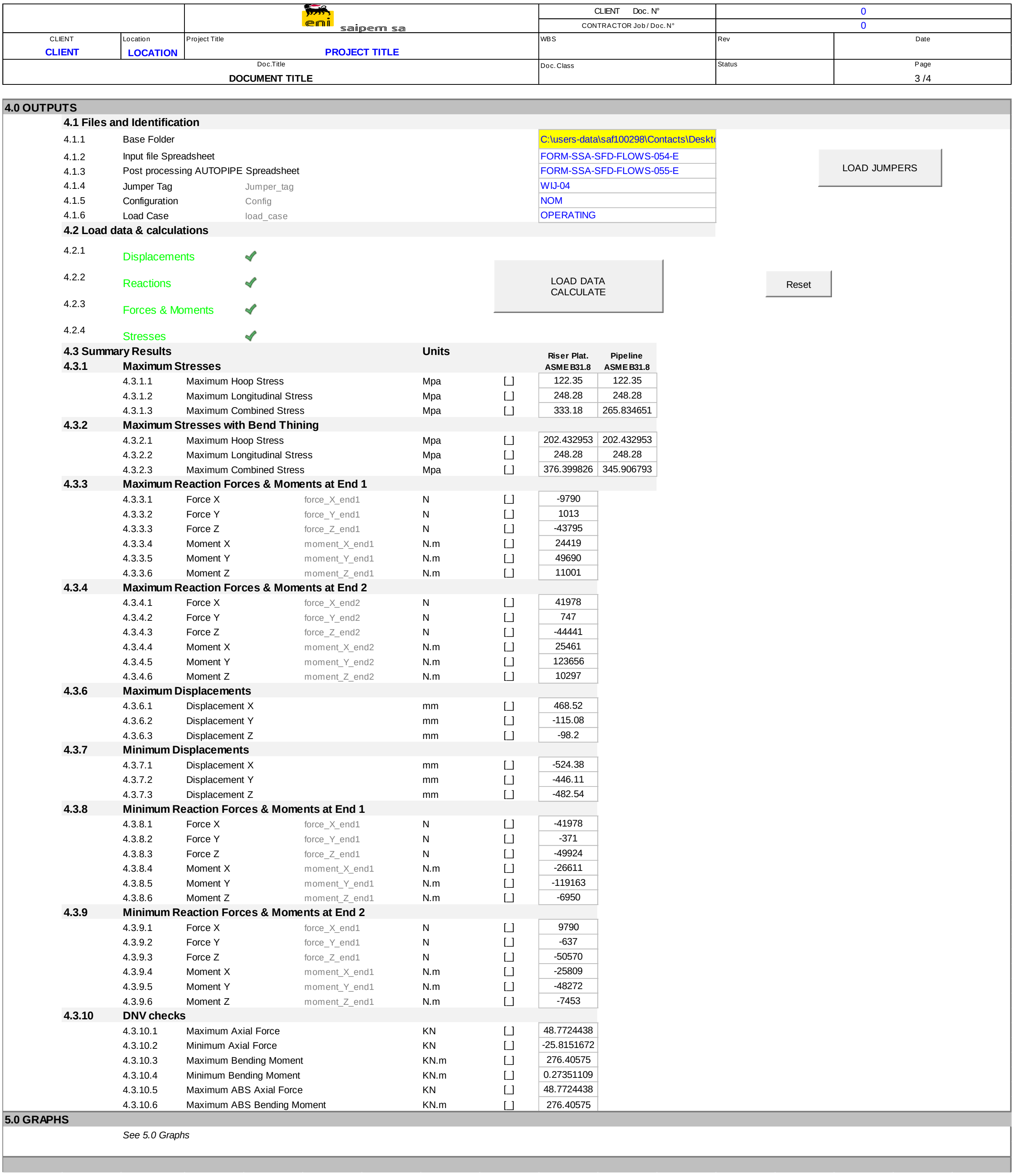
3) “OUTPUTS” WORKSHEET



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4.0 OUTPUTS

4.1 Files and Identification

4.1.1	Base Folder		C:\users-data\saf100298\Contacts\Deskt
4.1.2	Input file Spreadsheet		FORM-SSA-SFD-FLOWS-054-E
4.1.3	Post processing AUTOPIPE Spreadsheet		FORM-SSA-SFD-FLOWS-055-E
4.1.4	Jumper Tag	Jumper_tag	WIJ-04
4.1.5	Configuration	Config	NOM
4.1.6	Load Case	load_case	OPERATING

LOAD JUMPERS

4.2 Load data & calculations

4.2.1	Displacements	✓
4.2.2	Reactions	✓
4.2.3	Forces & Moments	✓
4.2.4	Stresses	✓

LOAD DATA
CALCULATE

Reset

4.3 Summary Results

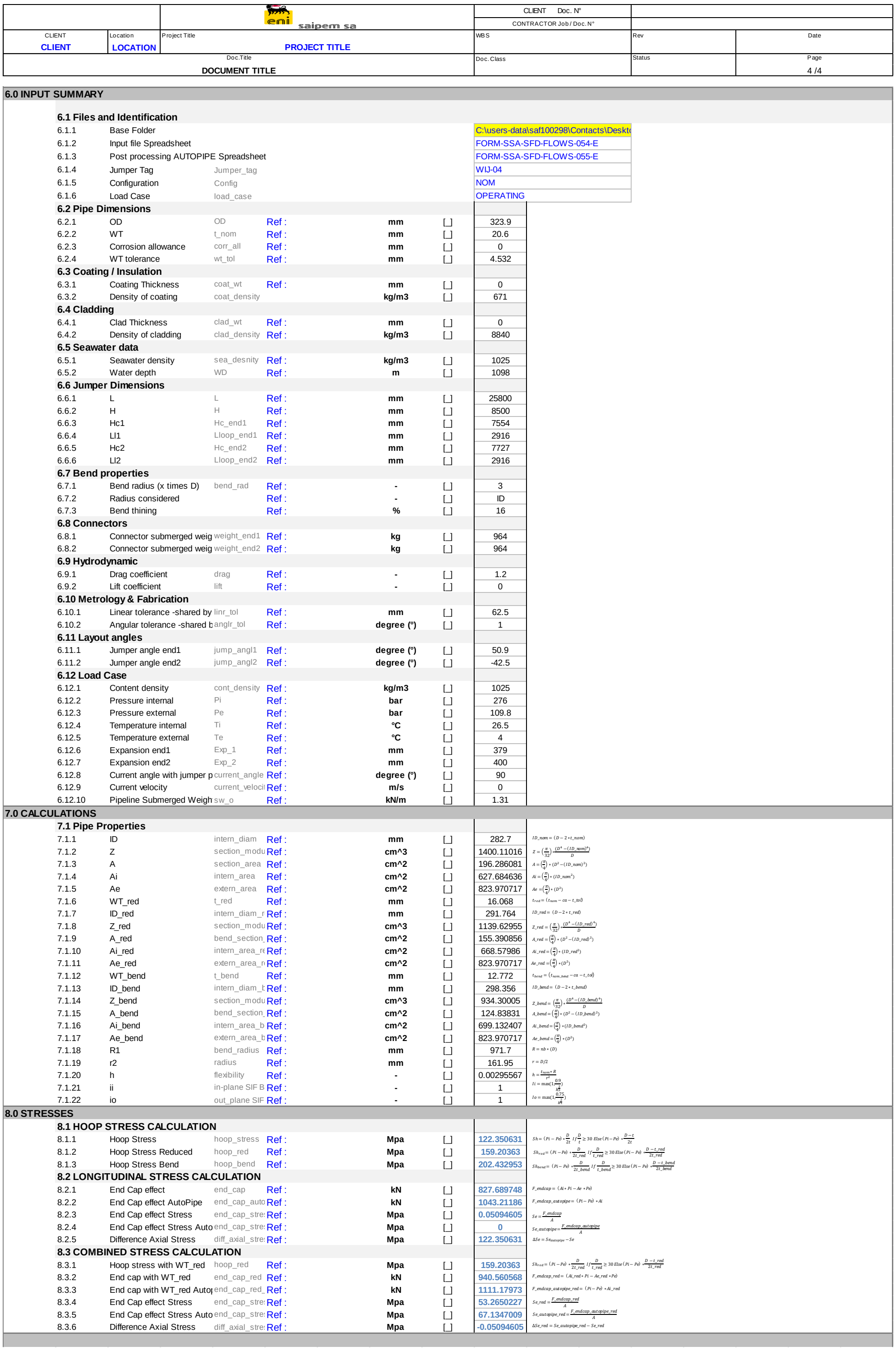
				Units		Riser Plat. ASME B31.8	Pipeline ASME B31.8
4.3.1	**Maximum Stresses**						
	4.3.1.1	Maximum Hoop Stress		Mpa	☐	122.35	122.35
	4.3.1.2	Maximum Longitudinal Stress		Mpa	☐	248.28	248.28
	4.3.1.3	Maximum Combined Stress		Mpa	☐	333.18	265.834651
4.3.2	**Maximum Stresses with Bend Thining**						
	4.3.2.1	Maximum Hoop Stress		Mpa	☐	202.432953	202.432953
	4.3.2.2	Maximum Longitudinal Stress		Mpa	☐	248.28	248.28
	4.3.2.3	Maximum Combined Stress		Mpa	☐	376.399826	345.906793
4.3.3	**Maximum Reaction Forces & Moments at End 1**						
	4.3.3.1	Force X	force_X_end1	N	☐	-9790	
	4.3.3.2	Force Y	force_Y_end1	N	☐	1013	
	4.3.3.3	Force Z	force_Z_end1	N	☐	-43795	
	4.3.3.4	Moment X	moment_X_end1	N.m	☐	24419	
	4.3.3.5	Moment Y	moment_Y_end1	N.m	☐	49690	
	4.3.3.6	Moment Z	moment_Z_end1	N.m	☐	11001	
4.3.4	**Maximum Reaction Forces & Moments at End 2**						
	4.3.4.1	Force X	force_X_end2	N	☐	41978	
	4.3.4.2	Force Y	force_Y_end2	N	☐	747	
	4.3.4.3	Force Z	force_Z_end2	N	☐	-44441	
	4.3.4.4	Moment X	moment_X_end2	N.m	☐	25461	
	4.3.4.5	Moment Y	moment_Y_end2	N.m	☐	123656	
	4.3.4.6	Moment Z	moment_Z_end2	N.m	☐	10297	
4.3.6	**Maximum Displacements**						
	4.3.6.1	Displacement X		mm	☐	468.52	
	4.3.6.2	Displacement Y		mm	☐	-115.08	
	4.3.6.3	Displacement Z		mm	☐	-98.2	
4.3.7	**Minimum Displacements**						
	4.3.7.1	Displacement X		mm	☐	-524.38	
	4.3.7.2	Displacement Y		mm	☐	-446.11	
	4.3.7.3	Displacement Z		mm	☐	-482.54	
4.3.8	**Minimum Reaction Forces & Moments at End 1**						
	4.3.8.1	Force X	force_X_end1	N	☐	-41978	
	4.3.8.2	Force Y	force_Y_end1	N	☐	-371	
	4.3.8.3	Force Z	force_Z_end1	N	☐	-49924	
	4.3.8.4	Moment X	moment_X_end1	N.m	☐	-26611	
	4.3.8.5	Moment Y	moment_Y_end1	N.m	☐	-119163	
	4.3.8.6	Moment Z	moment_Z_end1	N.m	☐	-6950	
4.3.9	**Minimum Reaction Forces & Moments at End 2**						
	4.3.9.1	Force X	force_X_end1	N	☐	9790	
	4.3.9.2	Force Y	force_Y_end1	N	☐	-637	
	4.3.9.3	Force Z	force_Z_end1	N	☐	-50570	
	4.3.9.4	Moment X	moment_X_end1	N.m	☐	-25809	
	4.3.9.5	Moment Y	moment_Y_end1	N.m	☐	-48272	
	4.3.9.6	Moment Z	moment_Z_end1	N.m	☐	-7453	
4.3.10	**DNV checks**						
	4.3.10.1	Maximum Axial Force		KN	☐	48.7724438	
	4.3.10.2	Minimum Axial Force		KN	☐	-25.8151672	
	4.3.10.3	Maximum Bending Moment		KN.m	☐	276.40575	
	4.3.10.4	Minimum Bending Moment		KN.m	☐	0.27351109	
	4.3.10.5	Maximum ABS Axial Force		KN	☐	48.7724438	
	4.3.10.6	Maximum ABS Bending Moment		KN.m	☐	276.40575	

5.0 GRAPHS

See 5.0 Graphs

The worksheet is completed for each load case. The tables summarize the stresses, forces and displacements obtained by the FEA programs. The VBA code isolating those values is based on the ordering of the output variables into tables and the computation of the maximum values in those tables.
The maximum deflection along Z should be checked with the seabed clearance in order to make sure that the jumper is not laying on the seabed.

4) “INPUTS” WORKSHEET



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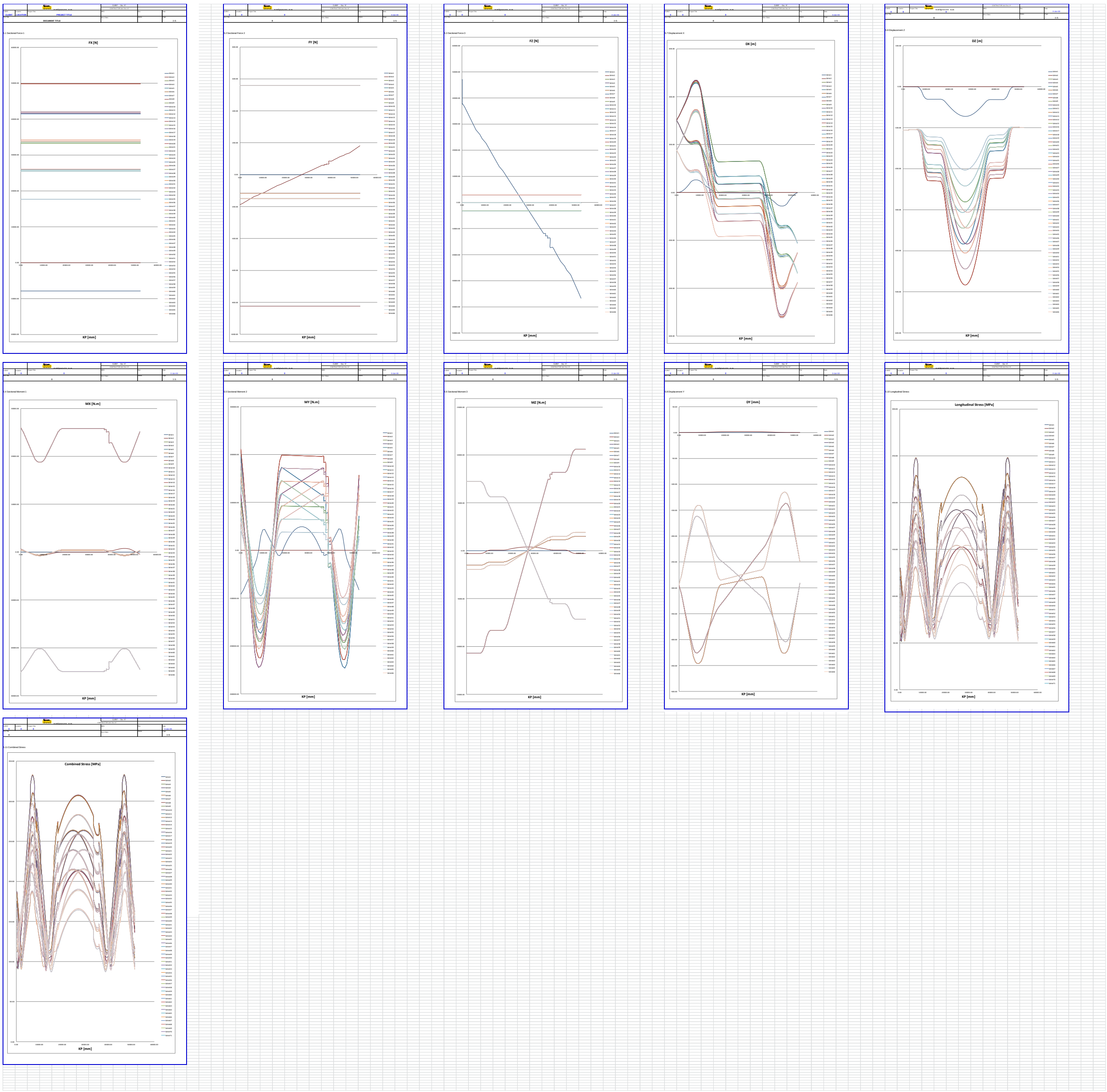
6.0 INPUT SUMMARY							
6.1 Files and Identification							
6.1.1	Base Folder					C:\users-data\saf100298\Contacts\Deskt	
6.1.2	Input file Spreadsheet					FORM-SSA-SFD-FLOWS-054-E	
6.1.3	Post processing AUTOPIPE Spreadsheet					FORM-SSA-SFD-FLOWS-055-E	
6.1.4	Jumper Tag	Jumper_tag				WIJ-04	
6.1.5	Configuration	Config				NOM	
6.1.6	Load Case	load_case				OPERATING	
6.2 Pipe Dimensions							
6.2.1	OD	OD	Ref :	**mm**	☐	323.9	
6.2.2	WT	t_nom	Ref :	**mm**	☐	20.6	
6.2.3	Corrosion allowance	corr_all	Ref :	**mm**	☐	0	
6.2.4	WT tolerance	wt_tol	Ref :	**mm**	☐	4.532	
6.3 Coating / Insulation							
6.3.1	Coating Thickness	coat_wt	Ref :	**mm**	☐	0	
6.3.2	Density of coating	coat_density		**kg/m3**	☐	671	
6.4 Cladding							
6.4.1	Clad Thickness	clad_wt	Ref :	**mm**	☐	0	
6.4.2	Density of cladding	clad_density	Ref :	**kg/m3**	☐	8840	
6.5 Seawater data							
6.5.1	Seawater density	sea_desnity	Ref :	**kg/m3**	☐	1025	
6.5.2	Water depth	WD	Ref :	**m**	☐	1098	
6.6 Jumper Dimensions							
6.6.1	L	L	Ref :	**mm**	☐	25800	
6.6.2	H	H	Ref :	**mm**	☐	8500	
6.6.3	Hc1	Hc_end1	Ref :	**mm**	☐	7554	
6.6.4	Ll1	Lloop_end1	Ref :	**mm**	☐	2916	
6.6.5	Hc2	Hc_end2	Ref :	**mm**	☐	7727	
6.6.6	Ll2	Lloop_end2	Ref :	**mm**	☐	2916	
6.7 Bend properties							
6.7.1	Bend radius (x times D)	bend_rad	Ref :	**-**	☐	3	
6.7.2	Radius considered		Ref :	**-**	☐	ID	
6.7.3	Bend thining		Ref :	**%**	☐	16	
6.8 Connectors							
6.8.1	Connector submerged weig	weight_end1	Ref :	**kg**	☐	964	
6.8.2	Connector submerged weig	weight_end2	Ref :	**kg**	☐	964	
6.9 Hydrodynamic							
6.9.1	Drag coefficient	drag	Ref :	**-**	☐	1.2	
6.9.2	Lift coefficient	lift	Ref :	**-**	☐	0	
6.10 Metrology & Fabrication							
6.10.1	Linear tolerance -shared by	linr_tol	Ref :	**mm**	☐	62.5	
6.10.2	Angular tolerance -shared b	anglr_tol	Ref :	**degree (°)**	☐	1	
6.11 Layout angles							
6.11.1	Jumper angle end1	jump_angl1	Ref :	**degree (°)**	☐	50.9	
6.11.2	Jumper angle end2	jump_angl2	Ref :	**degree (°)**	☐	-42.5	
6.12 Load Case							
6.12.1	Content density	cont_density	Ref :	**kg/m3**	☐	1025	
6.12.2	Pressure internal	Pi	Ref :	**bar**	☐	276	
6.12.3	Pressure external	Pe	Ref :	**bar**	☐	109.8	
6.12.4	Temperature internal	Ti	Ref :	**°C**	☐	26.5	
6.12.5	Temperature external	Te	Ref :	**°C**	☐	4	
6.12.6	Expansion end1	Exp_1	Ref :	**mm**	☐	379	
6.12.7	Expansion end2	Exp_2	Ref :	**mm**	☐	400	
6.12.8	Current angle with jumper p	current_angle	Ref :	**degree (°)**	☐	90	
6.12.9	Current velocity	current_veloci	Ref :	**m/s**	☐	0	
6.12.10	Pipeline Submerged Weigh	sw_o	Ref :	**kN/m**	☐	1.31	
7.0 CALCULATIONS							
7.1 Pipe Properties							
7.1.1	ID	intern_diam	Ref :	**mm**	☐	282.7	$ID\_nom = (D - 2 * t\_nom)$
7.1.2	Z	section_modu	Ref :	**cm^3**	☐	1400.11016	$Z = \left(\frac{\pi}{32}\right) * \frac{(D^4 - (ID\_nom)^4)}{D}$
7.1.3	A	section_area	Ref :	**cm^2**	☐	196.286081	$A = \left(\frac{\pi}{4}\right) * (D^2 - (ID\_nom)^2)$
7.1.4	Ai	intern_area	Ref :	**cm^2**	☐	627.684636	$Ai = \left(\frac{\pi}{4}\right) * (ID\_nom^2)$
7.1.5	Ae	extern_area	Ref :	**cm^2**	☐	823.970717	$Ae = \left(\frac{\pi}{4}\right) * (D^2)$
7.1.6	WT_red	t_red	Ref :	**mm**	☐	16.068	$t_{red} = (t_{nom} - ca - t\_tol)$
7.1.7	ID_red	intern_diam_r	Ref :	**mm**	☐	291.764	$ID\_red = (D - 2 * t\_red)$
7.1.8	Z_red	section_modu	Ref :	**cm^3**	☐	1139.62955	$Z\_red = \left(\frac{\pi}{32}\right) * \frac{(D^4 - (ID\_red)^4)}{D}$
7.1.9	A_red	bend_section_	Ref :	**cm^2**	☐	155.390856	$A\_red = \left(\frac{\pi}{4}\right) * (D^2 - (ID\_red)^2)$
7.1.10	Ai_red	intern_area_re	Ref :	**cm^2**	☐	668.57986	$Ai\_red = \left(\frac{\pi}{4}\right) * (ID\_red^2)$
7.1.11	Ae_red	extern_area_r	Ref :	**cm^2**	☐	823.970717	$Ae\_red = \left(\frac{\pi}{4}\right) * (D^2)$
7.1.12	WT_bend	t_bend	Ref :	**mm**	☐	12.772	$t_{bend} = (t_{nom\_bend} - ca - t\_tol)$
7.1.13	ID_bend	intern_diam_b	Ref :	**mm**	☐	298.356	$ID\_bend = (D - 2 * t\_bend)$
7.1.14	Z_bend	section_modu	Ref :	**cm^3**	☐	934.30005	$Z\_bend = \left(\frac{\pi}{32}\right) * \frac{(D^4 - (ID\_bend)^4)}{D}$
7.1.15	A_bend	bend_section_	Ref :	**cm^2**	☐	124.83831	$A\_bend = \left(\frac{\pi}{4}\right) * (D^2 - (ID\_bend)^2)$
7.1.16	Ai_bend	intern_area_b	Ref :	**cm^2**	☐	699.132407	$Ai\_bend = \left(\frac{\pi}{4}\right) * (ID\_bend^2)$
7.1.17	Ae_bend	extern_area_b	Ref :	**cm^2**	☐	823.970717	$Ae\_bend = \left(\frac{\pi}{4}\right) * (D^2)$
7.1.18	R1	bend_radius	Ref :	**mm**	☐	971.7	$R = nb * (D)$
7.1.19	r2	radius	Ref :	**mm**	☐	161.95	$r = D/2$
7.1.20	h	flexibility	Ref :	**-**	☐	0.00295567	$h = \frac{t_{nom} * R}{r^2}$
7.1.21	ii	in-plane SIF B	Ref :	**-**	☐	1	$Ii = \max(1, \frac{0.9}{h^{\frac{2}{3}}})$
7.1.22	io	out_plane SIF	Ref :	**-**	☐	1	$Io = \max(1, \frac{0.75}{h^{\frac{2}{3}}})$
8.0 STRESSES							
8.1 HOOP STRESS CALCULATION							
8.1.1	Hoop Stress	hoop_stress	Ref :	**Mpa**	☐	122.350631	$Sh = (Pi - Pe) * \frac{D}{2t}\ If \frac{D}{t} \geq 30\ Else\ (Pi - Pe) * \frac{D - t}{2t}$
8.1.2	Hoop Stress Reduced	hoop_red	Ref :	**Mpa**	☐	159.20363	$Sh_{red} = (Pi - Pe) * \frac{D}{2t\_red}\ If \frac{D}{t\_red} \geq 30\ Else\ (Pi - Pe) * \frac{D - t\_red}{2t\_red}$
8.1.3	Hoop Stress Bend	hoop_bend	Ref :	**Mpa**	☐	202.432953	$Sh_{bend} = (Pi - Pe) * \frac{D}{2t\_bend}\ If \frac{D}{t\_bend} \geq 30\ Else\ (Pi - Pe) * \frac{D - t\_bend}{2t\_bend}$
8.2 LONGITUDINAL STRESS CALCULATION							
8.2.1	End Cap effect	end_cap	Ref :	**kN**	☐	827.689748	$F\_endcap = (Ai * Pi - Ae * Pe)$
8.2.2	End Cap effect AutoPipe	end_cap_auto	Ref :	**kN**	☐	1043.21186	$F\_endcap\_autopipe = (Pi - Pe) * Ai$
8.2.3	End Cap effect Stress	end_cap_stre	Ref :	**Mpa**	☐	0.05094605	$Se = \frac{F\_endcap}{A}$
8.2.4	End Cap effect Stress Auto	end_cap_stre	Ref :	**Mpa**	☐	0	$Se\_autopipe = \frac{F\_endcap\_autopipe}{A}$
8.2.5	Difference Axial Stress	diff_axial_stre	Ref :	**Mpa**	☐	122.350631	$\Delta Se = Se_{autopipe} - Se$
8.3 COMBINED STRESS CALCULATION							
8.3.1	Hoop stress with WT_red	hoop_red	Ref :	**Mpa**	☐	159.20363	$Sh_{red} = (Pi - Pe) * \frac{D}{2t\_red}\ If \frac{D}{t\_red} \geq 30\ Else\ (Pi - Pe) * \frac{D - t\_red}{2t\_red}$
8.3.2	End cap with WT_red	end_cap_red	Ref :	**kN**	☐	940.560568	$F\_endcap\_red = (Ai\_red * Pi - Ae\_red * Pe)$
8.3.3	End cap with WT_red Autop	end_cap_red_	Ref :	**kN**	☐	1111.17973	$F\_endcap\_autopipe\_red = (Pi - Pe) * Ai\_red$
8.3.4	End Cap effect Stress	end_cap_stre	Ref :	**Mpa**	☐	53.2650227	$Se\_red = \frac{F\_endcap\_red}{A}$
8.3.5	End Cap effect Stress Auto	end_cap_stre	Ref :	**Mpa**	☐	67.1347009	$Se\_autopipe\_red = \frac{F\_endcap\_autopipe\_red}{A}$
8.3.6	Difference Axial Stress	diff_axial_stre	Ref :	**Mpa**	☐	-0.05094605	$\Delta Se\_red = Se\_autopipe\_red - Se\_red$

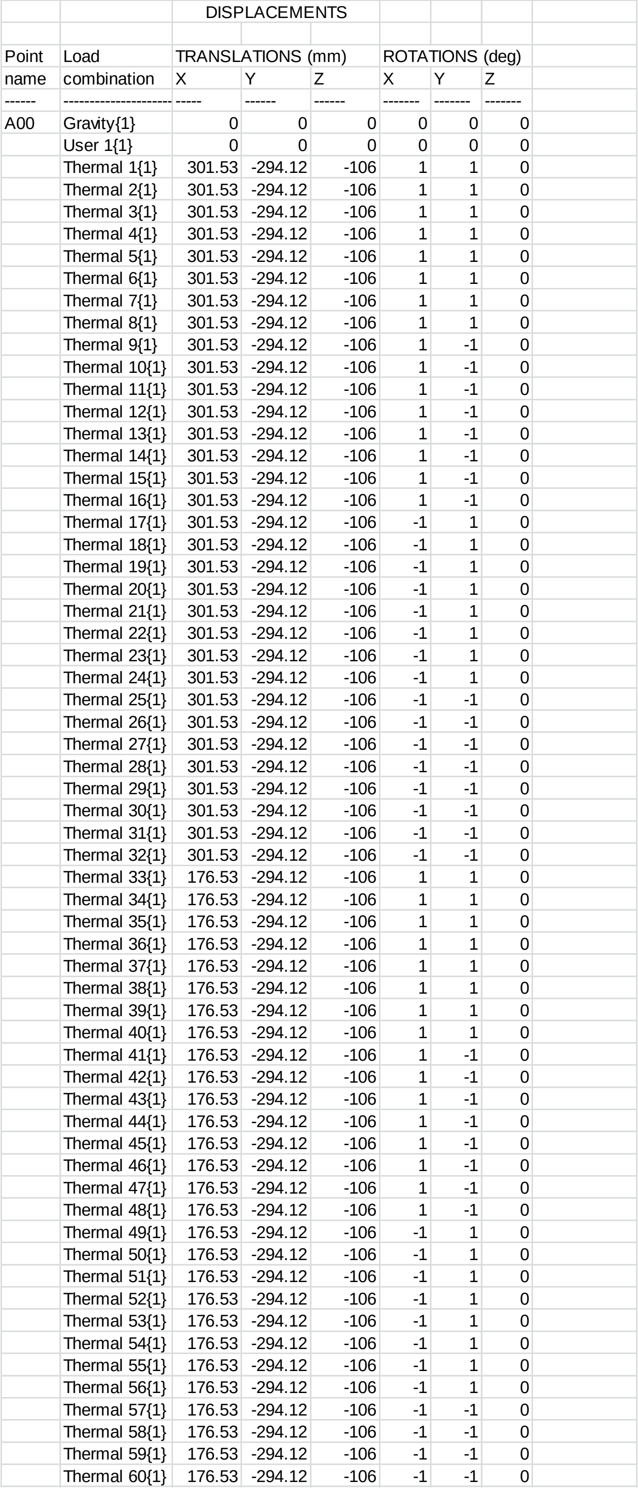
This worksheet computes the mechanical properties of the jumpers : section areas, section modulus, flexibility factor, in plane stress intensification factor, out of plane intensification factor. Additionally the hoop stress is calculated and the end cap effect is computed. Those results will be useful in the stress computations.

5) “GRAPHS” WORKSHEET



Variable variations along the jumper are been plotted simply for information purposes. Effective axial force, displacement DX, DY and DZ, Sectional forces SF1,SF2 and SF3 as well as sectional moments SM1,SM2 and SM3, Combined and Longitudinal Stresses are all gathered into graphs automatically.

6) “DISPLACEMENTS” WORKSHEET



		DISPLACEMENTS					
Point	Load	TRANSLATIONS (mm)			ROTATIONS (deg)		
name	combination	X	Y	Z	X	Y	Z
------	---------------------	-----	------	------	-------	-------	-------
A00	Gravity{1}	0	0	0	0	0	0
	User 1{1}	0	0	0	0	0	0
	Thermal 1{1}	301.53	-294.12	-106	1	1	0
	Thermal 2{1}	301.53	-294.12	-106	1	1	0
	Thermal 3{1}	301.53	-294.12	-106	1	1	0
	Thermal 4{1}	301.53	-294.12	-106	1	1	0
	Thermal 5{1}	301.53	-294.12	-106	1	1	0
	Thermal 6{1}	301.53	-294.12	-106	1	1	0
	Thermal 7{1}	301.53	-294.12	-106	1	1	0
	Thermal 8{1}	301.53	-294.12	-106	1	1	0
	Thermal 9{1}	301.53	-294.12	-106	1	-1	0
	Thermal 10{1}	301.53	-294.12	-106	1	-1	0
	Thermal 11{1}	301.53	-294.12	-106	1	-1	0
	Thermal 12{1}	301.53	-294.12	-106	1	-1	0
	Thermal 13{1}	301.53	-294.12	-106	1	-1	0
	Thermal 14{1}	301.53	-294.12	-106	1	-1	0
	Thermal 15{1}	301.53	-294.12	-106	1	-1	0
	Thermal 16{1}	301.53	-294.12	-106	1	-1	0
	Thermal 17{1}	301.53	-294.12	-106	-1	1	0
	Thermal 18{1}	301.53	-294.12	-106	-1	1	0
	Thermal 19{1}	301.53	-294.12	-106	-1	1	0
	Thermal 20{1}	301.53	-294.12	-106	-1	1	0
	Thermal 21{1}	301.53	-294.12	-106	-1	1	0
	Thermal 22{1}	301.53	-294.12	-106	-1	1	0
	Thermal 23{1}	301.53	-294.12	-106	-1	1	0
	Thermal 24{1}	301.53	-294.12	-106	-1	1	0
	Thermal 25{1}	301.53	-294.12	-106	-1	-1	0
	Thermal 26{1}	301.53	-294.12	-106	-1	-1	0
	Thermal 27{1}	301.53	-294.12	-106	-1	-1	0
	Thermal 28{1}	301.53	-294.12	-106	-1	-1	0
	Thermal 29{1}	301.53	-294.12	-106	-1	-1	0
	Thermal 30{1}	301.53	-294.12	-106	-1	-1	0
	Thermal 31{1}	301.53	-294.12	-106	-1	-1	0
	Thermal 32{1}	301.53	-294.12	-106	-1	-1	0
	Thermal 33{1}	176.53	-294.12	-106	1	1	0
	Thermal 34{1}	176.53	-294.12	-106	1	1	0
	Thermal 35{1}	176.53	-294.12	-106	1	1	0
	Thermal 36{1}	176.53	-294.12	-106	1	1	0
	Thermal 37{1}	176.53	-294.12	-106	1	1	0
	Thermal 38{1}	176.53	-294.12	-106	1	1	0
	Thermal 39{1}	176.53	-294.12	-106	1	1	0
	Thermal 40{1}	176.53	-294.12	-106	1	1	0
	Thermal 41{1}	176.53	-294.12	-106	1	-1	0
	Thermal 42{1}	176.53	-294.12	-106	1	-1	0
	Thermal 43{1}	176.53	-294.12	-106	1	-1	0
	Thermal 44{1}	176.53	-294.12	-106	1	-1	0
	Thermal 45{1}	176.53	-294.12	-106	1	-1	0
	Thermal 46{1}	176.53	-294.12	-106	1	-1	0
	Thermal 47{1}	176.53	-294.12	-106	1	-1	0
	Thermal 48{1}	176.53	-294.12	-106	1	-1	0
	Thermal 49{1}	176.53	-294.12	-106	-1	1	0
	Thermal 50{1}	176.53	-294.12	-106	-1	1	0
	Thermal 51{1}	176.53	-294.12	-106	-1	1	0
	Thermal 52{1}	176.53	-294.12	-106	-1	1	0
	Thermal 53{1}	176.53	-294.12	-106	-1	1	0
	Thermal 54{1}	176.53	-294.12	-106	-1	1	0
	Thermal 55{1}	176.53	-294.12	-106	-1	1	0
	Thermal 56{1}	176.53	-294.12	-106	-1	1	0
	Thermal 57{1}	176.53	-294.12	-106	-1	-1	0
	Thermal 58{1}	176.53	-294.12	-106	-1	-1	0
	Thermal 59{1}	176.53	-294.12	-106	-1	-1	0
	Thermal 60{1}	176.53	-294.12	-106	-1	-1	0

The importing options on excel has enabled to save the displacements and rotations for all the nodes of the model and all the load cases. The data can be used to check the results and the deformed shape of the pipeline. The maximum values are extracted and transferred in the OUTPUTS worksheet.

7) “REACTIONS” WORKSHEET

		RESTRAINT REACTIONS							
Point	Load		FORCES (N)			MOMENTS (N.m)			
name	combination	X	Y	Z	Result	X	Y	Z	Result
------	----------------------- -	-----	------	------	------	-------	-------	-------	-------
A00	Anchor Tag No.: <None	>							
	Gravity{1}	7868	0	-46972	47627	0	92010	0	92010
	User 1{1}	0	188	0	188	-634	0	295	699
	Thermal 1{1}	-33623	117	3160	33771	-404	-165765	1512	165772
	Thermal 2{1}	-42036	117	144	42037	-404	-181969	1512	181976
	Thermal 3{1}	-33623	825	3160	33781	-25977	-165765	10706	168129
	Thermal 4{1}	-42036	825	144	42045	-25977	-181969	10706	184125
	Thermal 5{1}	-41433	117	3177	41554	-404	-194969	1512	194976
	Thermal 6{1}	-49846	117	161	49846	-404	-211173	1512	211179
	Thermal 7{1}	-41433	825	3177	41562	-25977	-194969	10706	196984
	Thermal 8{1}	-49846	825	161	49853	-25977	-211173	10706	213034
	Thermal 9{1}	-25468	117	81	25468	-404	-71525	1512	71542
	Thermal 10{1}	-33881	117	-2935	34008	-404	-87729	1512	87743
	Thermal 11{1}	-25468	825	81	25481	-25977	-71525	10706	76845
	Thermal 12{1}	-33881	825	-2935	34018	-25977	-87729	10706	92118
	Thermal 13{1}	-33277	117	97	33277	-404	-100729	1512	100741
	Thermal 14{1}	-41691	117	-2919	41793	-404	-116933	1512	116944
	Thermal 15{1}	-33277	825	97	33288	-25977	-100729	10706	104574
	Thermal 16{1}	-41691	825	-2919	41801	-25977	-116933	10706	120261
	Thermal 17{1}	-33623	-559	3160	33776	25053	-165765	-7245	167804
	Thermal 18{1}	-42036	-559	144	42040	25053	-181969	-7245	183828
	Thermal 19{1}	-33623	150	3160	33771	-520	-165765	1949	165777
	Thermal 20{1}	-42036	150	144	42037	-520	-181969	1949	181980
	Thermal 21{1}	-41433	-559	3177	41558	25053	-194969	-7245	196706
	Thermal 22{1}	-49846	-559	161	49849	25053	-211173	-7245	212778
	Thermal 23{1}	-41433	150	3177	41554	-520	-194969	1949	194980
	Thermal 24{1}	-49846	150	161	49846	-520	-211173	1949	211183
	Thermal 25{1}	-25468	-559	81	25474	25053	-71525	-7245	76131
	Thermal 26{1}	-33881	-559	-2935	34012	25053	-87729	-7245	91523
	Thermal 27{1}	-25468	150	81	25468	-520	-71525	1949	71553
	Thermal 28{1}	-33881	150	-2935	34008	-520	-87729	1949	87752
	Thermal 29{1}	-33277	-559	97	33282	25053	-100729	-7245	104051
	Thermal 30{1}	-41691	-559	-2919	41796	25053	-116933	-7245	119806
	Thermal 31{1}	-33277	150	97	33278	-520	-100729	1949	100749
	Thermal 32{1}	-41691	150	-2919	41793	-520	-116933	1949	116950
	Thermal 33{1}	-25813	117	3143	26004	-404	-136561	1512	136570
	Thermal 34{1}	-34227	117	128	34227	-404	-152765	1512	152773
	Thermal 35{1}	-25813	825	3143	26017	-25977	-136561	10706	139421
	Thermal 36{1}	-34227	825	128	34237	-25977	-152765	10706	155327
	Thermal 37{1}	-33623	117	3160	33771	-404	-165765	1512	165772
	Thermal 38{1}	-42036	117	144	42037	-404	-181969	1512	181976
	Thermal 39{1}	-33623	825	3160	33781	-25977	-165765	10706	168129
	Thermal 40{1}	-42036	825	144	42045	-25977	-181969	10706	184125
	Thermal 41{1}	-17658	117	64	17658	-404	-42320	1512	42349
	Thermal 42{1}	-26071	117	-2952	26238	-404	-58524	1512	58545
	Thermal 43{1}	-17658	825	64	17677	-25977	-42320	10706	50798
	Thermal 44{1}	-26071	825	-2952	26251	-25977	-58524	10706	64919
	Thermal 45{1}	-25468	117	81	25468	-404	-71525	1512	71542
	Thermal 46{1}	-33881	117	-2935	34008	-404	-87729	1512	87743
	Thermal 47{1}	-25468	825	81	25481	-25977	-71525	10706	76845
	Thermal 48{1}	-33881	825	-2935	34018	-25977	-87729	10706	92118
	Thermal 49{1}	-25813	-559	3143	26010	25053	-136561	-7245	139029

The reaction worksheet summarizes the reaction forces and moments for the two extremities of the jumper. The envelope values may be obtained from this table as allowable load checks should be performed to make sure that the connectors support the Jumper.

8) “FORCES&MOMENTS” WORKSHEET

GLOBAL FORCES & MOMENTS

Point name	**Load combination**	**FORCES (N)** **X**	**Y**	**Z**	**MOMENTS (N.m)** **Result**	**X**	**Y**	**Z**	**Result**
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A00	Gravity{1}	-7868	0	46972	47627	0	-92010	0	92010
	User 1{1}	0	-188	0	188	634	0	-295	699
	Thermal 1{1}	33623	-117	-3160	33771	404	165765	-1512	165772
	Thermal 2{1}	42036	-117	-144	42037	404	181969	-1512	181976
	Thermal 3{1}	33623	-825	-3160	33781	25977	165765	-10706	168129
	Thermal 4{1}	42036	-825	-144	42045	25977	181969	-10706	184125
	Thermal 5{1}	41433	-117	-3177	41554	404	194969	-1512	194976
	Thermal 6{1}	49846	-117	-161	49846	404	211173	-1512	211179
	Thermal 7{1}	41433	-825	-3177	41562	25977	194969	-10706	196984
	Thermal 8{1}	49846	-825	-161	49853	25977	211173	-10706	213034
	Thermal 9{1}	25468	-117	-81	25468	404	71525	-1512	71542
	Thermal 10{1}	33881	-117	2935	34008	404	87729	-1512	87743
	Thermal 11{1}	25468	-825	-81	25481	25977	71525	-10706	76845
	Thermal 12{1}	33881	-825	2935	34018	25977	87729	-10706	92118
	Thermal 13{1}	33277	-117	-97	33277	404	100729	-1512	100741
	Thermal 14{1}	41691	-117	2919	41793	404	116933	-1512	116944
	Thermal 15{1}	33277	-825	-97	33288	25977	100729	-10706	104574
	Thermal 16{1}	41691	-825	2919	41801	25977	116933	-10706	120261
	Thermal 17{1}	33623	559	-3160	33776	-25053	165765	7245	167804
	Thermal 18{1}	42036	559	-144	42040	-25053	181969	7245	183828
	Thermal 19{1}	33623	-150	-3160	33771	520	165765	-1949	165777
	Thermal 20{1}	42036	-150	-144	42037	520	181969	-1949	181980
	Thermal 21{1}	41433	559	-3177	41558	-25053	194969	7245	196706
	Thermal 22{1}	49846	559	-161	49849	-25053	211173	7245	212778
	Thermal 23{1}	41433	-150	-3177	41554	520	194969	-1949	194980
	Thermal 24{1}	49846	-150	-161	49846	520	211173	-1949	211183
	Thermal 25{1}	25468	559	-81	25474	-25053	71525	7245	76131
	Thermal 26{1}	33881	559	2935	34012	-25053	87729	7245	91523
	Thermal 27{1}	25468	-150	-81	25468	520	71525	-1949	71553
	Thermal 28{1}	33881	-150	2935	34008	520	87729	-1949	87752
	Thermal 29{1}	33277	559	-97	33282	-25053	100729	7245	104051
	Thermal 30{1}	41691	559	2919	41796	-25053	116933	7245	119806
	Thermal 31{1}	33277	-150	-97	33278	520	100729	-1949	100749
	Thermal 32{1}	41691	-150	2919	41793	520	116933	-1949	116950
	Thermal 33{1}	25813	-117	-3143	26004	404	136561	-1512	136570
	Thermal 34{1}	34227	-117	-128	34227	404	152765	-1512	152773
	Thermal 35{1}	25813	-825	-3143	26017	25977	136561	-10706	139421
	Thermal 36{1}	34227	-825	-128	34237	25977	152765	-10706	155327
	Thermal 37{1}	33623	-117	-3160	33771	404	165765	-1512	165772
	Thermal 38{1}	42036	-117	-144	42037	404	181969	-1512	181976
	Thermal 39{1}	33623	-825	-3160	33781	25977	165765	-10706	168129
	Thermal 40{1}	42036	-825	-144	42045	25977	181969	-10706	184125
	Thermal 41{1}	17658	-117	-64	17658	404	42320	-1512	42349
	Thermal 42{1}	26071	-117	2952	26238	404	58524	-1512	58545
	Thermal 43{1}	17658	-825	-64	17677	25977	42320	-10706	50798
	Thermal 44{1}	26071	-825	2952	26251	25977	58524	-10706	64919
	Thermal 45{1}	25468	-117	-81	25468	404	71525	-1512	71542
	Thermal 46{1}	33881	-117	2935	34008	404	87729	-1512	87743
	Thermal 47{1}	25468	-825	-81	25481	25977	71525	-10706	76845
	Thermal 48{1}	33881	-825	2935	34018	25977	87729	-10706	92118
	Thermal 49{1}	25813	559	-3143	26010	-25053	136561	7245	139029
	Thermal 50{1}	34227	559	-128	34232	-25053	152765	7245	154975

Sectional forces and moments are obtained for each node of the model in every load case condition. Thus it is possible to compute the stresses equations described in part 3.1.2 of this report.

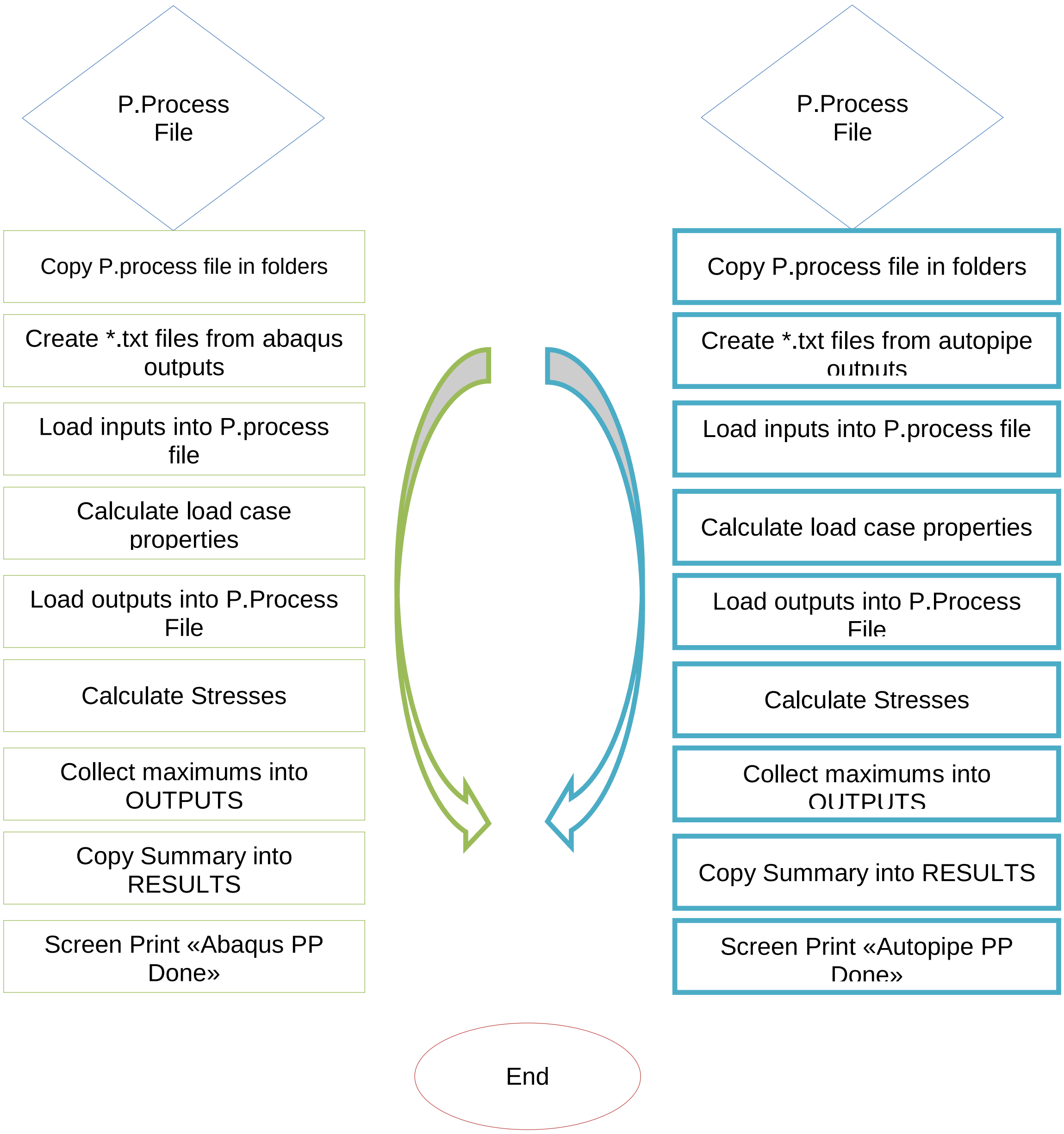
9) “STRESSES” WORKSHEET

FORCES (KN) & MOMENTS (KN.m)							LONGITUDINAL STRESS CALCULATIONS(Mpa) RISERS AND PIPELINES			COMBINED STRESS CALCULATIONS(Mpa) RISERS					COMBINED STRESS CALCULATIONS(Mpa) PIPELINES				
Elem	ESF1	SF2	SF3	SM1	SM2	SM3	Axial_stress [Mpa]	R_Bending_moment [Mpa]	Long. Stress [Mpa]	Torsional_stress [Mpa]	Axial_stress_Wtred [Mpa]	R_Bending_moment_Wtred [Mpa]	Long. Stress [Mpa]	Comb. Stress [Mpa]	Torsional_stress [Mpa]	Axial_stress_Wtred [Mpa]	R_Bending_moment_Wtred [Mpa]	Long. Stress [Mpa]	Comb. Stress [Mpa]
------	---------------	------	------	------	------	-------	$Sa = \frac{F_{-endcap,autopipe} - ESF1}{A}$	$Sb = \frac{\sqrt{((Io * SM2)^2 + (Ii * SM3)^2)}}{Z}$	$SL = Max(Sa\text{-}Sb, Sa+Sb)$	$St\_red = \frac{SM1}{2 * Z\_red}$	$Sa\_red = \frac{F_{-endcap,autopipe\_red} - ESF1}{A\_red}$	$Sb\_red = \frac{\sqrt{((Io * SM2)^2 + (Ii * SM3)^2)}}{Z\_red}$	$SL = Max(Sa\_red\text{-}Sb\_red, Sa\_red+Sb\_red)$	$S_{comb} = 2 * \sqrt{\left(\left(\frac{Sh_{red} - (Sa\_red - Sb\_red)}{2}\right)^2 + St\_red^2\right)}$	$St = \frac{SM1}{2 * Z}$	$Sa = \frac{F_{-endcap,autopipe} - ESF1}{A}$	$Sb = \frac{\sqrt{((Io * SM2)^2 + (Ii * SM3)^2)}}{Z}$	$SL = Max(Sa\text{-}Sb, Sa+Sb)$	$S_{comb} = 2 * \sqrt{\left(\left(\frac{Sh - (Sa - Sb)}{2}\right)^2 + St^2\right)}$
1	6.66E-16	-1.88E-01	-2.22E-17	5.01E-01	-1.09E-16	3.77E-01	0.00	0.27	0.27	0.22	0.00	0.33	0.33	0.55	0.18	0.00	0.27	0.27	0.45
2	1.11E-16	-1.87E-01	-2.22E-17	4.75E-01	-8.93E-17	3.77E-01	0.00	0.27	0.27	0.21	0.00	0.33	0.33	0.53	0.17	0.00	0.27	0.27	0.43
3	4.44E-16	-1.86E-01	-2.21E-17	4.34E-01	-7.81E-17	3.77E-01	0.00	0.27	0.27	0.19	0.00	0.33	0.33	0.50	0.15	0.00	0.27	0.27	0.41
4	1.39E-16	-1.84E-01	-2.20E-17	3.78E-01	-7.29E-17	3.77E-01	0.00	0.27	0.27	0.17	0.00	0.33	0.33	0.47	0.14	0.00	0.27	0.27	0.38
5	1.67E-16	-1.82E-01	-2.19E-17	3.23E-01	-5.64E-17	3.77E-01	0.00	0.27	0.27	0.14	0.00	0.33	0.33	0.44	0.12	0.00	0.27	0.27	0.35
6	-1.39E-17	-1.77E-01	-2.16E-17	1.95E-01	-4.42E-17	3.77E-01	0.00	0.27	0.27	0.09	0.00	0.33	0.33	0.37	0.07	0.00	0.27	0.27	0.30
7	1.73E-18	-1.70E-01	-2.11E-17	-3.14E-03	-2.70E-17	3.77E-01	0.00	0.27	0.27	0.00	0.00	0.33	0.33	0.33	0.00	0.00	0.27	0.27	0.27
8	-5.55E-17	-1.63E-01	-2.07E-17	-1.93E-01	-9.54E-18	3.77E-01	0.00	0.27	0.27	-0.08	0.00	0.33	0.33	0.37	-0.07	0.00	0.27	0.27	0.30
9	-1.67E-16	-1.55E-01	-2.02E-17	-3.74E-01	4.86E-17	3.77E-01	0.00	0.27	0.27	-0.16	0.00	0.33	0.33	0.47	-0.13	0.00	0.27	0.27	0.38
10	0	-0.1478	-1.98E-17	-5.47E-01	1.13E-17	3.77E-01	0.00	0.27	0.27	-0.24	0.00	0.33	0.33	0.58	-0.20	0.00	0.27	0.27	0.47
11	-2.50E-16	-1.44E-01	-1.95E-17	-6.09E-01	2.52E-17	4.25E-01	0.00	0.30	0.30	-0.27	0.00	0.37	0.37	0.65	-0.22	0.00	0.30	0.30	0.53
12	0.00E+00	-1.43E-01	-1.92E-17	-5.54E-01	4.94E-17	5.17E-01	0.00	0.37	0.37	-0.24	0.00	0.45	0.45	0.66	-0.20	0.00	0.37	0.37	0.54
13	4.44E-16	-1.42E-01	-1.84E-17	-4.85E-01	3.30E-17	5.98E-01	0.00	0.43	0.43	-0.21	0.00	0.53	0.53	0.68	-0.17	0.00	0.43	0.43	0.55
14	-1.67E-16	-1.41E-01	-1.71E-17	-4.05E-01	5.20E-17	6.68E-01	0.00	0.48	0.48	-0.18	0.00	0.59	0.59	0.69	-0.14	0.00	0.48	0.48	0.56
15	5.55E-17	-1.40E-01	-1.54E-17	-3.14E-01	6.51E-17	7.25E-01	0.00	0.52	0.52	-0.14	0.00	0.64	0.64	0.69	-0.11	0.00	0.52	0.52	0.56
16	1.25E-16	-1.39E-01	-1.34E-17	-2.15E-01	6.51E-17	7.67E-01	0.00	0.55	0.55	-0.09	0.00	0.67	0.67	0.70	-0.08	0.00	0.55	0.55	0.57
17	5.55E-17	-1.39E-01	-1.10E-17	-1.11E-01	7.37E-17	7.92E-01	0.00	0.57	0.57	-0.05	0.00	0.70	0.70	0.70	-0.04	0.00	0.57	0.57	0.57
18	1.47E-17	-1.38E-01	-8.37E-18	-3.62E-03	7.03E-17	8.01E-01	0.00	0.57	0.57	0.00	0.00	0.70	0.70	0.70	0.00	0.00	0.57	0.57	0.57
19	6.94E-17	-1.37E-01	-5.56E-18	1.04E-01	7.85E-17	7.93E-01	0.00	0.57	0.57	0.05	0.00	0.70	0.70	0.70	0.04	0.00	0.57	0.57	0.57
20	8.33E-17	-1.36E-01	-2.62E-18	2.08E-01	7.03E-17	7.69E-01	0.00	0.55	0.55	0.09	0.00	0.67	0.67	0.70	0.07	0.00	0.55	0.55	0.57
21	-1.53E-16	1.35E-01	1.13E-18	-2.43E-01	-6.98E-17	7.51E-01	0.00	0.54	0.54	-0.11	0.00	0.66	0.66	0.69	-0.09	0.00	0.54	0.54	0.56
22	-2.78E-17	1.33E-01	1.13E-18	-2.10E-01	-6.94E-17	7.51E-01	0.00	0.54	0.54	-0.09	0.00	0.66	0.66	0.68	-0.07	0.00	0.54	0.54	0.56
23	1.39E-17	0.1316	1.13E-18	-1.78E-01	-7.42E-17	7.51E-01	0.00	0.54	0.54	-0.08	0.00	0.66	0.66	0.68	-0.06	0.00	0.54	0.54	0.55
24	2.71E-16	1.30E-01	1.13E-18	-1.46E-01	-8.09E-17	7.51E-01	0.00	0.54	0.54	-0.06	0.00	0.66	0.66	0.67	-0.05	0.00	0.54	0.54	0.55
25	-4.16E-17	1.28E-01	1.13E-18	-1.14E-01	-6.79E-17	7.51E-01	0.00	0.54	0.54	-0.05	0.00	0.66	0.66	0.67	-0.04	0.00	0.54	0.54	0.54
26	-1.39E-17	-1.27E-01	3.21E-19	1.49E-01	7.55E-17	7.41E-01	0.00	0.53	0.53	0.07	0.00	0.65	0.65	0.66	0.05	0.00	0.53	0.53	0.54
27	1.39E-17	-1.26E-01	3.21E-18	2.46E-01	8.54E-17	7.10E-01	0.00	0.51	0.51	0.11	0.00	0.62	0.62	0.66	0.09	0.00	0.51	0.51	0.54
28	1.39E-16	-1.26E-01	5.99E-18	3.37E-01	7.81E-17	6.64E-01	0.00	0.47	0.47	0.15	0.00	0.58	0.58	0.65	0.12	0.00	0.47	0.47	0.53
29	1.11E-16	-1.25E-01	8.62E-18	4.20E-01	9.71E-17	6.04E-01	0.00	0.43	0.43	0.18	0.00	0.53	0.53	0.65	0.15	0.00	0.43	0.43	0.53
30	-3.05E-16	-1.24E-01	1.10E-17	4.93E-01	4.94E-17	5.32E-01	0.00	0.38	0.38	0.22	0.00	0.47	0.47	0.64	0.18	0.00	0.38	0.38	0.52
31	-1.67E-16	-1.23E-01	1.31E-17	5.54E-01	2.43E-17	4.50E-01	0.00	0.32	0.32	0.24	0.00	0.39	0.39	0.63	0.20	0.00	0.32	0.32	0.51
32	-2.78E-16	-1.22E-01	1.49E-17	6.02E-01	1.99E-17	3.59E-01	0.00	0.26	0.26	0.26	0.00	0.31	0.31	0.61	0.21	0.00	0.26	0.26	0.50
33	-3.33E-16	-1.21E-01	1.63E-17	6.34E-01	4.51E-17	2.62E-01	0.00	0.19	0.19	0.28	0.00	0.23	0.23	0.60	0.23	0.00	0.19	0.19	0.49
34	-3.33E-16	-1.20E-01	1.73E-17	6.51E-01	7.98E-17	1.60E-01	0.00	0.11	0.11	0.29	0.00	0.14	0.14	0.59	0.23	0.00	0.11	0.11	0.48
35	1.67E-16	-1.20E-01	1.79E-17	6.53E-01	3.47E-17	5.78E-02	0.00	0.04	0.04	0.29	0.00	0.05	0.05	0.57	0.23	0.00	0.04	0.04	0.47
36	-2.78E-16	1.15E-01	-1.78E-17	-5.80E-01	-3.56E-17	7.01E-03	0.00	0.01	0.01	-0.25	0.00	0.01	0.01	0.51	-0.21	0.00	0.01	0.01	0.41

Starting from the sectional forces and moments, the Longitudinal and Combined stresses are calculated. Two options are followed : whether the Jumper is designed in a Riser condition of ASME B31.8 or in a Pipeline condition. The calculations are a bit different (see Part 3.2). In the Riser case the reduced thickness of the pipe (minus the corrosion allowance and the fabrication tolerance) is used while in the Pipeline case the nominal thickness is selected for the combined stress calc.

4.3.1 Process Flowchart

The post processing spreadsheet is efficient thanks to a VBA code developed (Attachement D). The following process flow presents the steps done by the spreadsheet.



With :

5. RESULTS AND STUDY CASE

The FEA design tools developed (three excel spreadsheets) have been tested with a Saipem project. The accuracy of the results and the quality of the result summary were brought into inquirement. The spreadsheets have shown to be very efficient for the design of M-shaped Jumpers. The design department has validated the outputs obtained.

5.1 12” WATER INJECTION JUMPER : BONGA NORTHWEST, SHELL NIGERIA PRODUCTION

BONGA North West is located in Nigeria in approximately 900 to 1200 meters of water to the west and north of the BONGA FPSO. The project scope consists of 6 wells (4 off producers and 2 injectors) tied back to the BONGA MAIN infrastructure, but with subsea infrastructure capacity for 12 subsea wells.

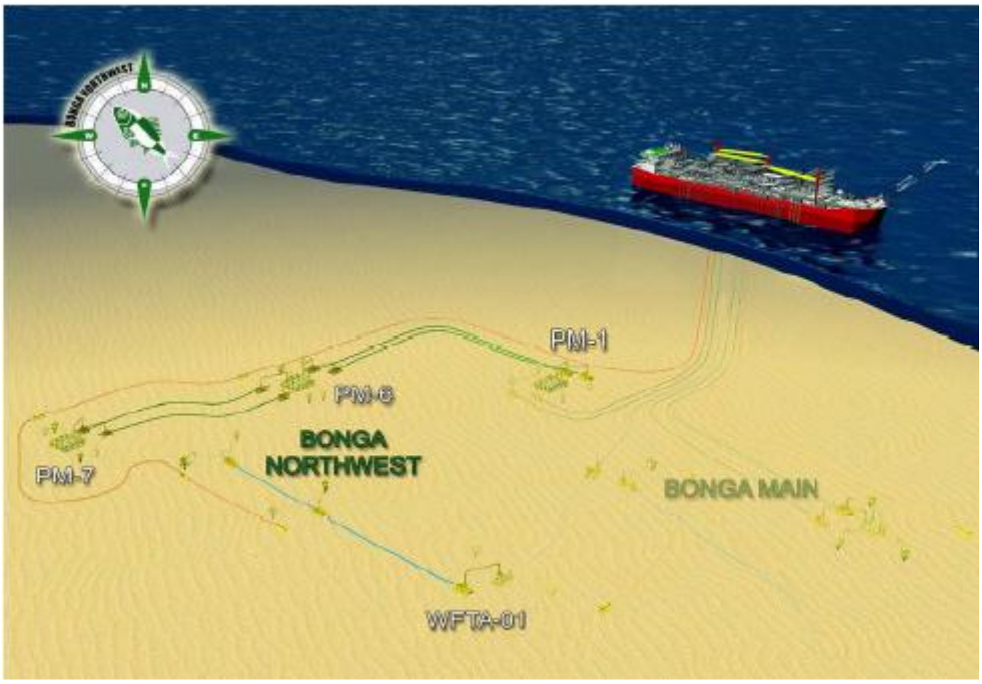


Figure 52. Bonga Northwest Field Layout

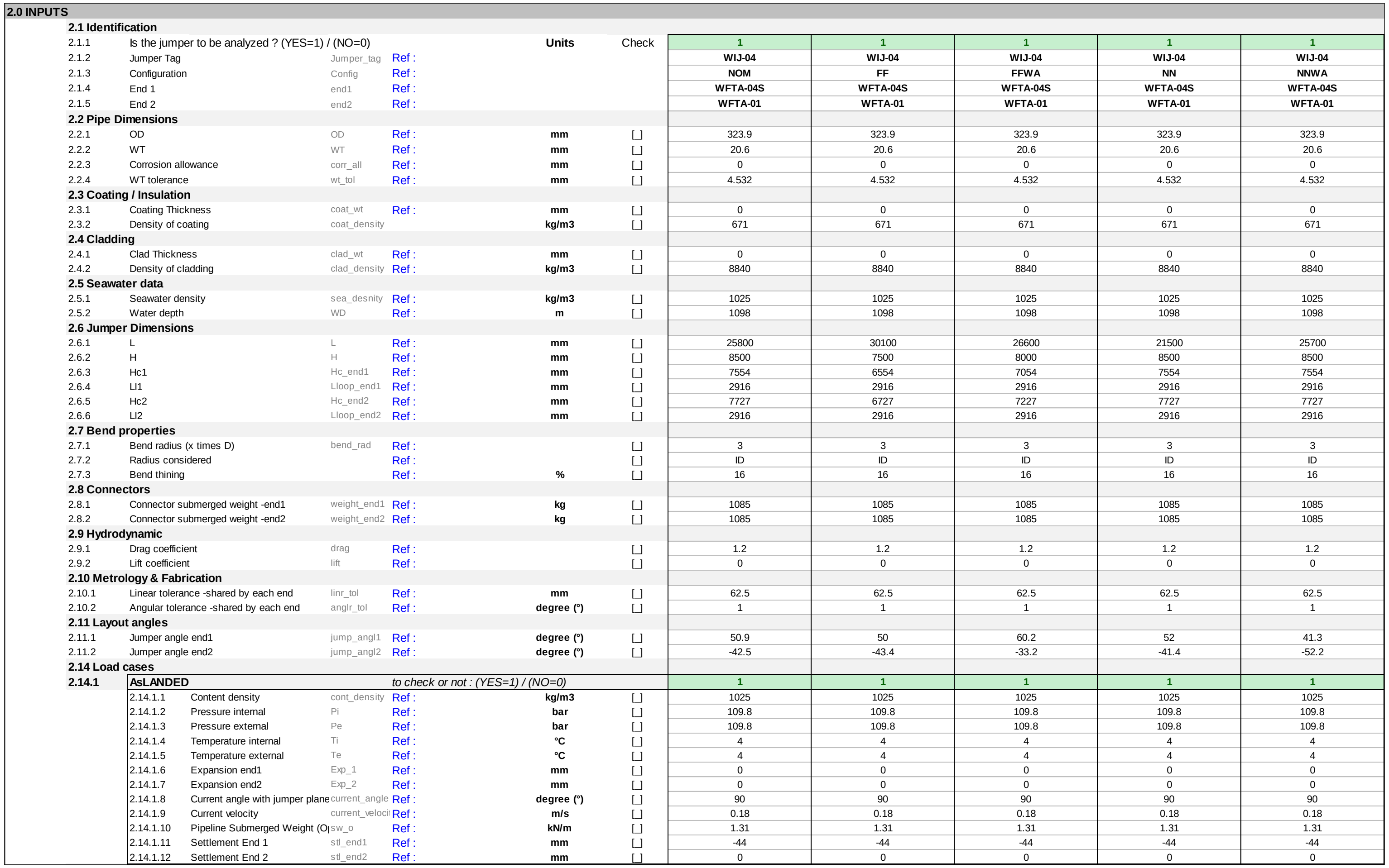
The production lines will be pipe-in-pipe insulated to control wax and prevent hydrate formation. A water-injection flowline will transport treated seawater from the BONGA Main FPSO via the existing BONGA Main’s water injection system to several subsea injection wells. The flowlines between the existing BONGA Main subsea system and the new BONGA NW subsea well manifolds will be

- Production Flowlines (222 mm) ~8.75” ID, PIP
- Water Injection Flowline 12” OD

The design of the 12” Water Injection M-shaped Jumper was performed by the Flowline Department of Saipem Eni Paris. A Comparison will be performed between the results obtained by the previous engineering team and the results given by the newly developed spreadsheets.

Intensive use of the design report of the project Ref[12] has been made in order to collect all the input parameters. Both the As landed condition and operating one were designed by the department. The spreadsheet capacity of analysing the different configurations (Nominal, Far Far, FFWA, Near Near and NNWA) automatically is a great advantage. The input spreadsheet was completed with the correct parameters (dimensions, weights, tolerances, expansions, pressures, current, settlements).

In the As landed condition the spreadsheet is completed as below :



2.0 INPUTS										
2.1 Identification										
2.1.1	Is the jumper to be analyzed ? (YES=1) / (NO=0)			**Units**	Check	**1**	**1**	**1**	**1**	**1**
2.1.2	Jumper Tag	Jumper_tag	Ref :			**WIJ-04**	**WIJ-04**	**WIJ-04**	**WIJ-04**	**WIJ-04**
2.1.3	Configuration	Config	Ref :			**NOM**	**FF**	**FFWA**	**NN**	**NNWA**
2.1.4	End 1	end1	Ref :			**WFTA-04S**	**WFTA-04S**	**WFTA-04S**	**WFTA-04S**	**WFTA-04S**
2.1.5	End 2	end2	Ref :			**WFTA-01**	**WFTA-01**	**WFTA-01**	**WFTA-01**	**WFTA-01**
2.2 Pipe Dimensions										
2.2.1	OD	OD	Ref :	**mm**	☐	323.9	323.9	323.9	323.9	323.9
2.2.2	WT	WT	Ref :	**mm**	☐	20.6	20.6	20.6	20.6	20.6
2.2.3	Corrosion allowance	corr_all	Ref :	**mm**	☐	0	0	0	0	0
2.2.4	WT tolerance	wt_tol	Ref :	**mm**	☐	4.532	4.532	4.532	4.532	4.532
2.3 Coating / Insulation										
2.3.1	Coating Thickness	coat_wt	Ref :	**mm**	☐	0	0	0	0	0
2.3.2	Density of coating	coat_density		**kg/m3**	☐	671	671	671	671	671
2.4 Cladding										
2.4.1	Clad Thickness	clad_wt	Ref :	**mm**	☐	0	0	0	0	0
2.4.2	Density of cladding	clad_density	Ref :	**kg/m3**	☐	8840	8840	8840	8840	8840
2.5 Seawater data										
2.5.1	Seawater density	sea_desnity	Ref :	**kg/m3**	☐	1025	1025	1025	1025	1025
2.5.2	Water depth	WD	Ref :	**m**	☐	1098	1098	1098	1098	1098
2.6 Jumper Dimensions										
2.6.1	L	L	Ref :	**mm**	☐	25800	30100	26600	21500	25700
2.6.2	H	H	Ref :	**mm**	☐	8500	7500	8000	8500	8500
2.6.3	Hc1	Hc_end1	Ref :	**mm**	☐	7554	6554	7054	7554	7554
2.6.4	Ll1	Lloop_end1	Ref :	**mm**	☐	2916	2916	2916	2916	2916
2.6.5	Hc2	Hc_end2	Ref :	**mm**	☐	7727	6727	7227	7727	7727
2.6.6	Ll2	Lloop_end2	Ref :	**mm**	☐	2916	2916	2916	2916	2916
2.7 Bend properties										
2.7.1	Bend radius (x times D)	bend_rad	Ref :		☐	3	3	3	3	3
2.7.2	Radius considered		Ref :		☐	ID	ID	ID	ID	ID
2.7.3	Bend thining		Ref :	**%**	☐	16	16	16	16	16
2.8 Connectors										
2.8.1	Connector submerged weight -end1	weight_end1	Ref :	**kg**	☐	1085	1085	1085	1085	1085
2.8.2	Connector submerged weight -end2	weight_end2	Ref :	**kg**	☐	1085	1085	1085	1085	1085
2.9 Hydrodynamic										
2.9.1	Drag coefficient	drag	Ref :		☐	1.2	1.2	1.2	1.2	1.2
2.9.2	Lift coefficient	lift	Ref :		☐	0	0	0	0	0
2.10 Metrology & Fabrication										
2.10.1	Linear tolerance -shared by each end	linr_tol	Ref :	**mm**	☐	62.5	62.5	62.5	62.5	62.5
2.10.2	Angular tolerance -shared by each end	anglr_tol	Ref :	**degree (°)**	☐	1	1	1	1	1
2.11 Layout angles										
2.11.1	Jumper angle end1	jump_angl1	Ref :	**degree (°)**	☐	50.9	50	60.2	52	41.3
2.11.2	Jumper angle end2	jump_angl2	Ref :	**degree (°)**	☐	-42.5	-43.4	-33.2	-41.4	-52.2
2.14 Load cases										
2.14.1	**AsLANDED**		*to check or not : (YES=1) / (NO=0)*			**1**	**1**	**1**	**1**	**1**
2.14.1.1	Content density	cont_density	Ref :	**kg/m3**	☐	1025	1025	1025	1025	1025
2.14.1.2	Pressure internal	Pi	Ref :	**bar**	☐	109.8	109.8	109.8	109.8	109.8
2.14.1.3	Pressure external	Pe	Ref :	**bar**	☐	109.8	109.8	109.8	109.8	109.8
2.14.1.4	Temperature internal	Ti	Ref :	**°C**	☐	4	4	4	4	4
2.14.1.5	Temperature external	Te	Ref :	**°C**	☐	4	4	4	4	4
2.14.1.6	Expansion end1	Exp_1	Ref :	**mm**	☐	0	0	0	0	0
2.14.1.7	Expansion end2	Exp_2	Ref :	**mm**	☐	0	0	0	0	0
2.14.1.8	Current angle with jumper plane	current_angle	Ref :	**degree (°)**	☐	90	90	90	90	90
2.14.1.9	Current velocity	current_veloci	Ref :	**m/s**	☐	0.18	0.18	0.18	0.18	0.18
2.14.1.10	Pipeline Submerged Weight (O	sw_o	Ref :	**kN/m**	☐	1.31	1.31	1.31	1.31	1.31
2.14.1.11	Settlement End 1	stl_end1	Ref :	**mm**	☐	-44	-44	-44	-44	-44
2.14.1.12	Settlement End 2	stl_end2	Ref :	**mm**	☐	0	0	0	0	0

Figure 53. Input Spreadsheet Bonga NorthWest

The jumper is evaluated to satisfy the structure allowable criteria and ASME B31.8 Chap VIII criteria. The following tables present the stresses obtained in the previous project and by the automatic spreadsheets. The differences are below 4%, thus the model is validated.

Comparison Autopipe LONGITUDINAL Stress [MPa]

		Bonga North West	New Spreadsheet	Difference [%]
As Landed	**Nominal**	-112	115	2.7
Operating		249	249	0
As Landed	**Far Far**	-125	127	1.6
Operating		269	273	1.5
As Landed	**Near Near**	-106	110	3.8
Operating		253	257	1.6
As Landed	**FFWA**	-115	117	1.7
Operating		254	260	2.4
As Landed	**NNWA**	-112	114	1.8
Operating		243	249	2.5

Comparison Autopipe COMBINED Stress [MPa]

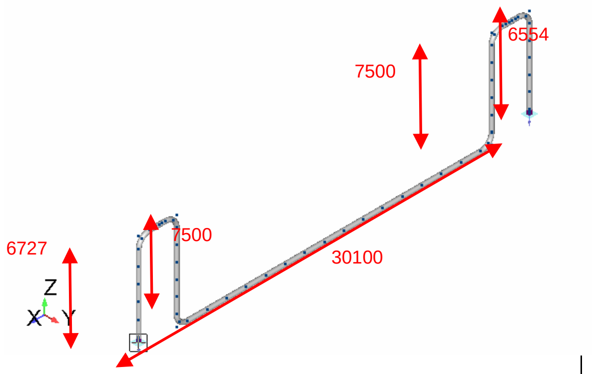
		Bonga North West	New Spreadsheet	Difference [%]
As Landed	**Nominal**	138	141	2.1
Operating		342	335	2.0
As Landed	**Far Far**	153	156	1.9
Operating		366	365	0.3
As Landed	**Near Near**	131	136	3.8
Operating		347	344	0.8
As Landed	**FFWA**	142	143	0.7
Operating		348	348	0
As Landed	**NNWA**	138	141	2.1
Operating		334	334	0

Consequently as the allowable longitudinal and combined stresses are (see section 1.2 ASME code):

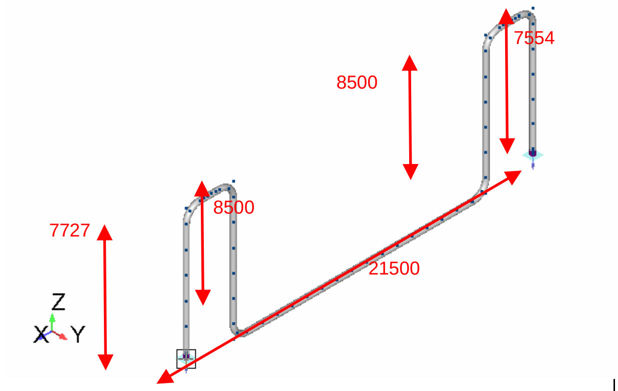
$$Long_{allowable} = 0.8 * SMYS = 359\ Mpa$$

$$Comb_{allowable} = 0.9 * SMYS = 403\ Mpa$$

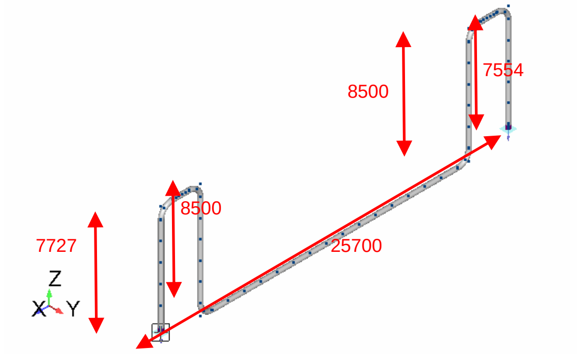
The heights of each configuration have been correctly designed. The following figures represent the different configurations designed and tested additionally to the nominal case.



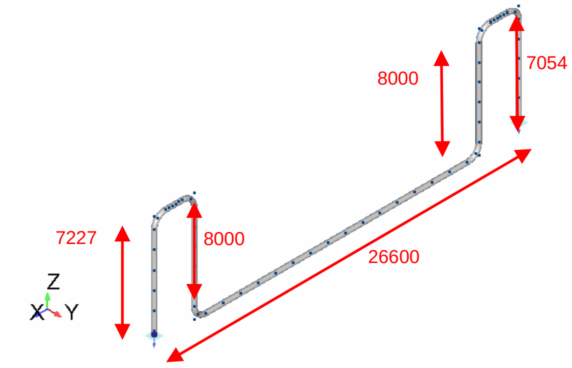
Far Far Configuration



Near Near Configuration



NNWA Configuration



FFWA Configuration

The Jumper loop heights are selected so that the stress check are respected. As previously said, a longer jumper main span (Far Far) will induce more compensation of the loads by deflection of the main straight. Consequently less elevated loop are allowed.

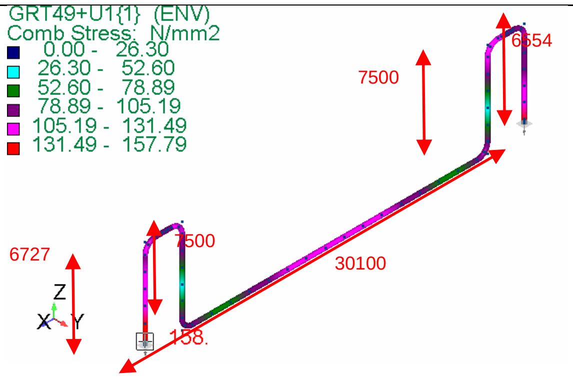
The reaction loads at the extremities are also collected and compared to the values given in the Design Report. When it comes to check the allowable loads on the connector, the force FZ, the moment MZ, the maximum vector sum of in-plane and out of plane bending moments MT, and the maximum vector sum of the shear force components FX and FY are almost identical.to the results obtained during the Bonga North West project. Difference is below 4%.

Reactions Loads FZ [kN] at End 1 (WFTA-04S)

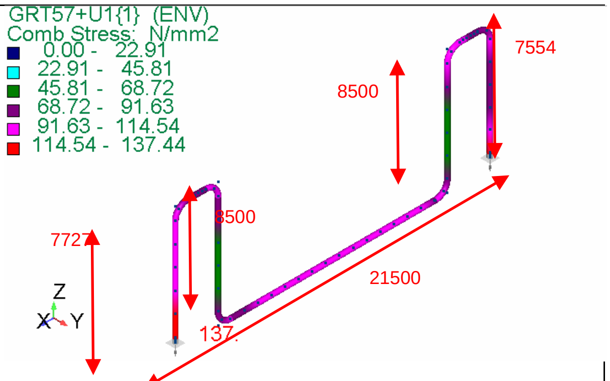
		Bonga North West	New Spreadsheet	Difference [%]
As Landed	**Nominal**	49.5	49.8	0.7
Operating		49.7	50	0.76
As Landed	**Far Far**	49.3	49.7	0.8
Operating		49.4	49.9	0.9
As Landed	**Near Near**	47.5	47.8	0.7
Operating		47.8	48.2	0.7
As Landed	**FFWA**	48.7	49	0.8
Operating		48.9	49.3	0.8
As Landed	**NNWA**	49.6	49.8	0.4
Operating		49.6	50	0.8

Reactions Loads MZ [kN.m] at End 1 (WFTA-04S)				
		Bonga North West	**New Spreadsheet**	**Difference [%]**
As Landed	**Nominal**	0	0	0
Operating		9	9.4	4.8
As Landed	**Far Far**	0	0	0
Operating		5.7	6.6	16.5
As Landed	**Near Near**	0	0	0
Operating		12.5	13.5	7.8
As Landed	**FFWA**	0	0	0
Operating		15	15.6	3.9
As Landed	**NNWA**	0	0	0
Operating		11.7	12.1	3.4

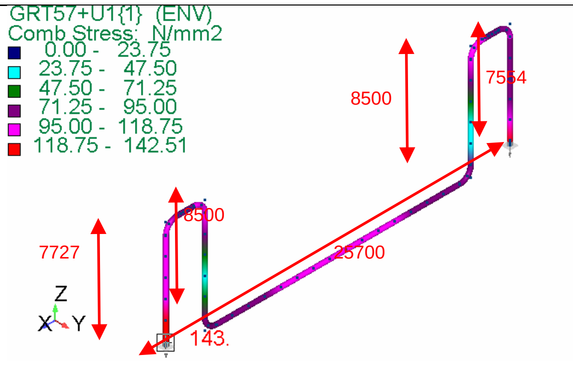
As expected the stresses along the jumper are maximum at the anchor locations because of the rigidity of such locations that have to hold the deformation of the structure.



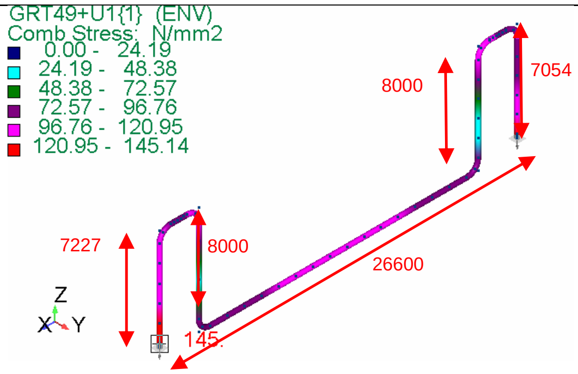
Far Far Configuration, Combined Stress



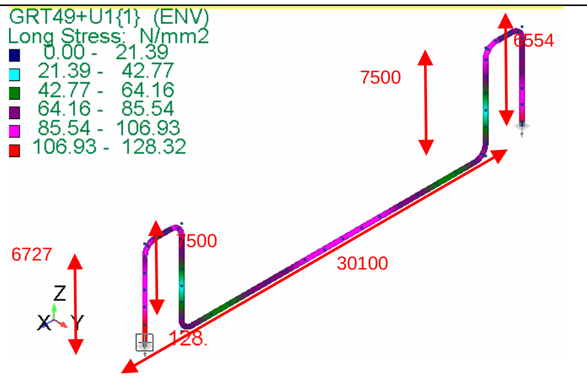
Near Near Configuration, Combined Stress



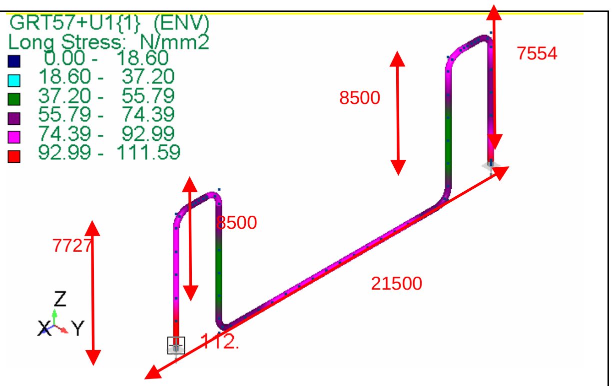
NNWA Configuration, Combined Stress



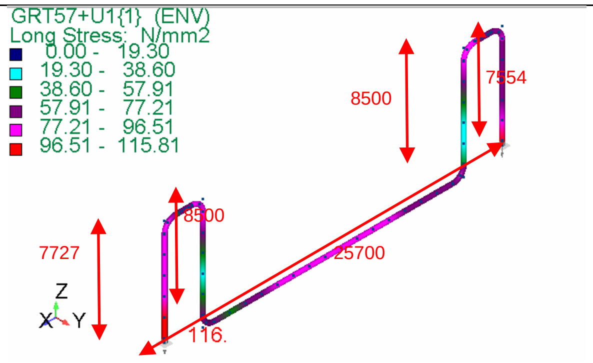
FFWA Configuration, Combined Stress



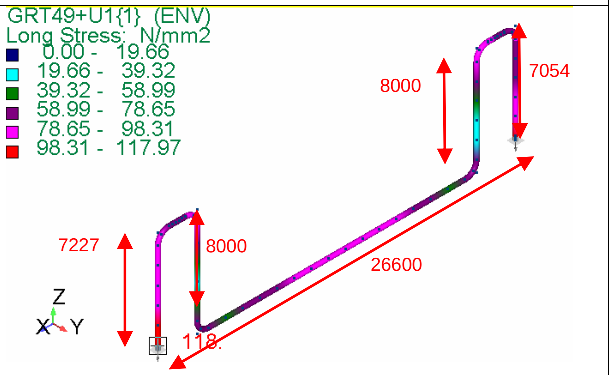
Far Far Configuration, Longitudinal Stress



Near Near Configuration, Longitudinal Stress

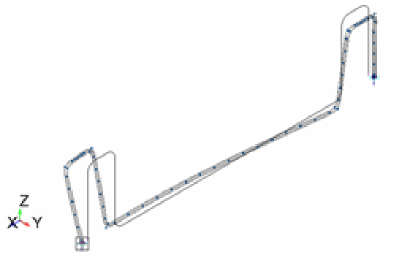


NNWA Configuration, Longitudinal Stress

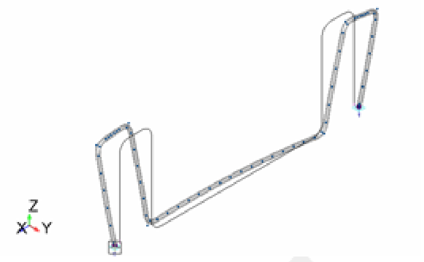


FFWA Configuration, Longitudinal Stress

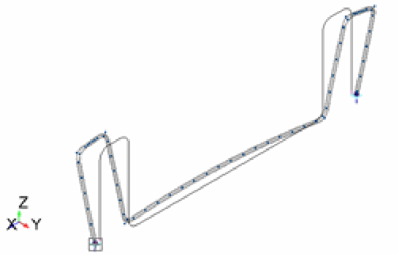
The Far Far configuration is the most stressed one. Indeed the free spanning of the main straight is applying a load that have an influence on fixed pup piece at the extremities. Reliance on the seabed would change the situation. Here below, the displacements cases implying most important stresses are represented.



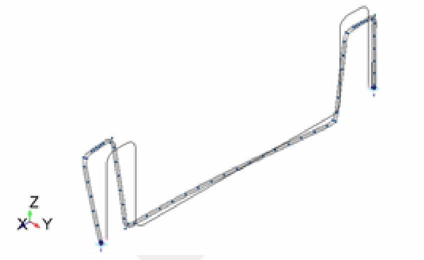
Far Far Configuration, GRT49U



Near Near Configuration, GRT57U



NNWA Configuration, GRT57U



FFWA Configuration, GRT49U

The project has also been done on Abaqus. However no direct comparison can be conducted. Indeed the two software may be presenting 10/20% differences in the stresses values. The more accurate model of bends on Abaqus is accounting for such differences, indeed the number of nodes in the bend is more important in Abaqus models. Autopipe limits the number of nodes in the bends to three only.

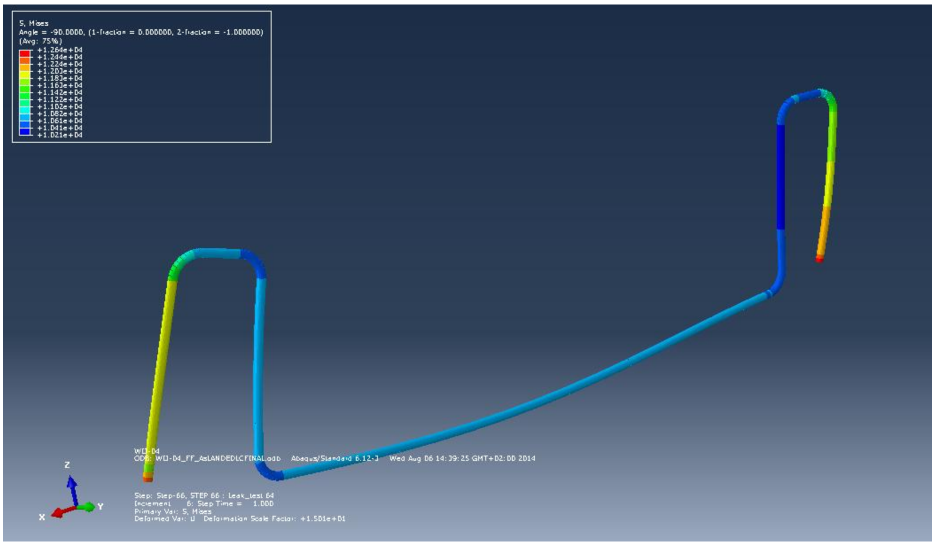


Figure 54. Abaqus model of Bonga Northwest

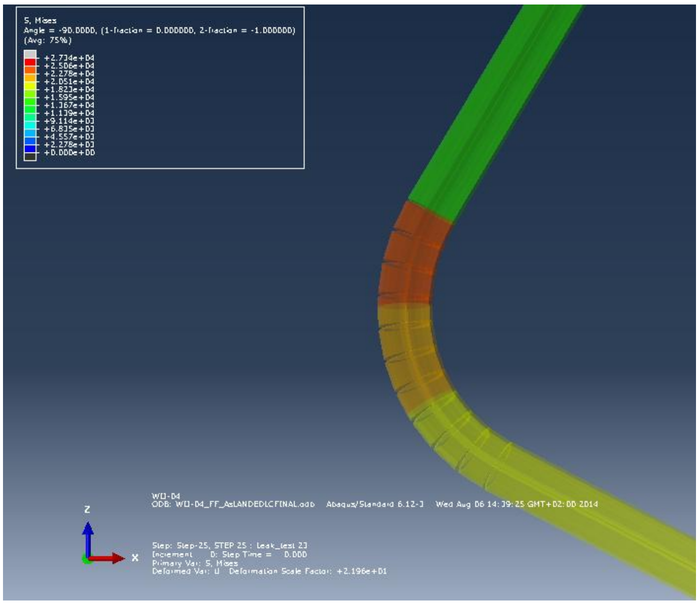


Figure 55. Bend close up in load case GRT27U

6. CONCLUSION

A Jumper system was designed and optimized. The structure under exam was a previous M-shaped Water Injection Jumper from the Bonga Northwest project. The work done in the development of automatic processing design spreadsheets have been efficient and appreciable for the design of this pipeline.

Because of the wide range of tolerances, expansions and installation uncertainties, the design of Jumper and Spools has to include multiple load cases conditions and geometric configurations. The subsea engineering industry is requiring the use of FEA programs (Abaqus, Autopipe) and the analysis time range has to be reduced as much as possible in order to meet schedule and cost reduction objectives. In this context, the development of three spreadsheets that generate the input files for Abaqus & Autopipe as well as the post processing actions are important improvements. The spreadsheets created have been validated internally.

Among the code checks, AMSE B31.8 and DNV OS-F101 are the most important ones. Several conditions of the life cycle of the jumper were tested. Pressure and temperature environmental conditions in the As Landed, Hydrotest, Leak Test, Operating and Shut Down cases were verified in terms of allowable stresses.

When dealing with Jumper and Spool design, engineers are willing to favour rapidity of design procedures in order to suit with the “last minute” fabrication time. Indeed those structures have to accommodate the tolerances and displacement of the lines. Consequently their definitive design is selected only once all the field equipment are installed. Cost savings can be achieved if a quicker design procedure is available.

Finally, the overall performance of the spreadsheets have been proven even if improvement in the 3 Dimensional spools is still an ongoing task.

REFERENCE

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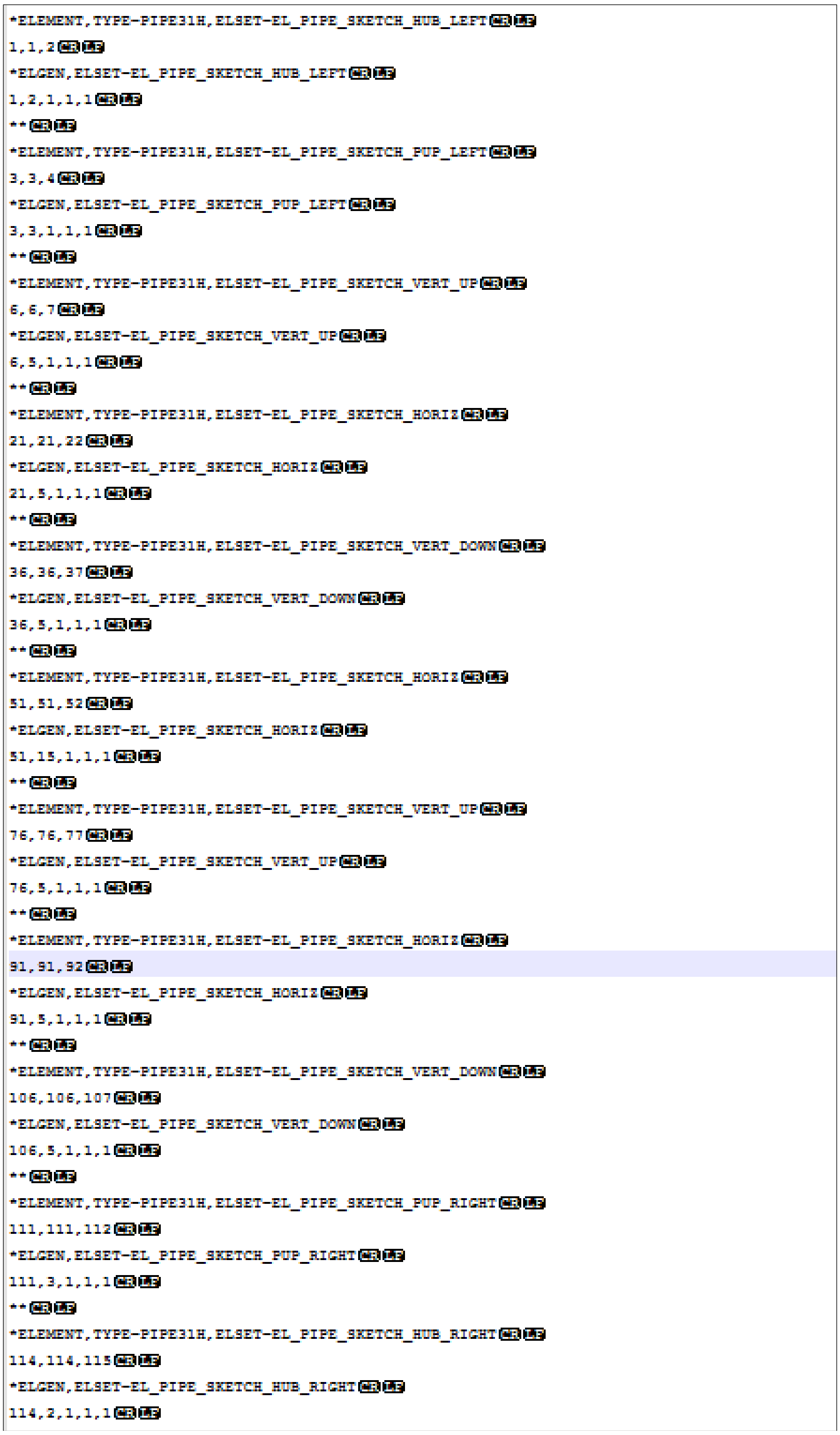
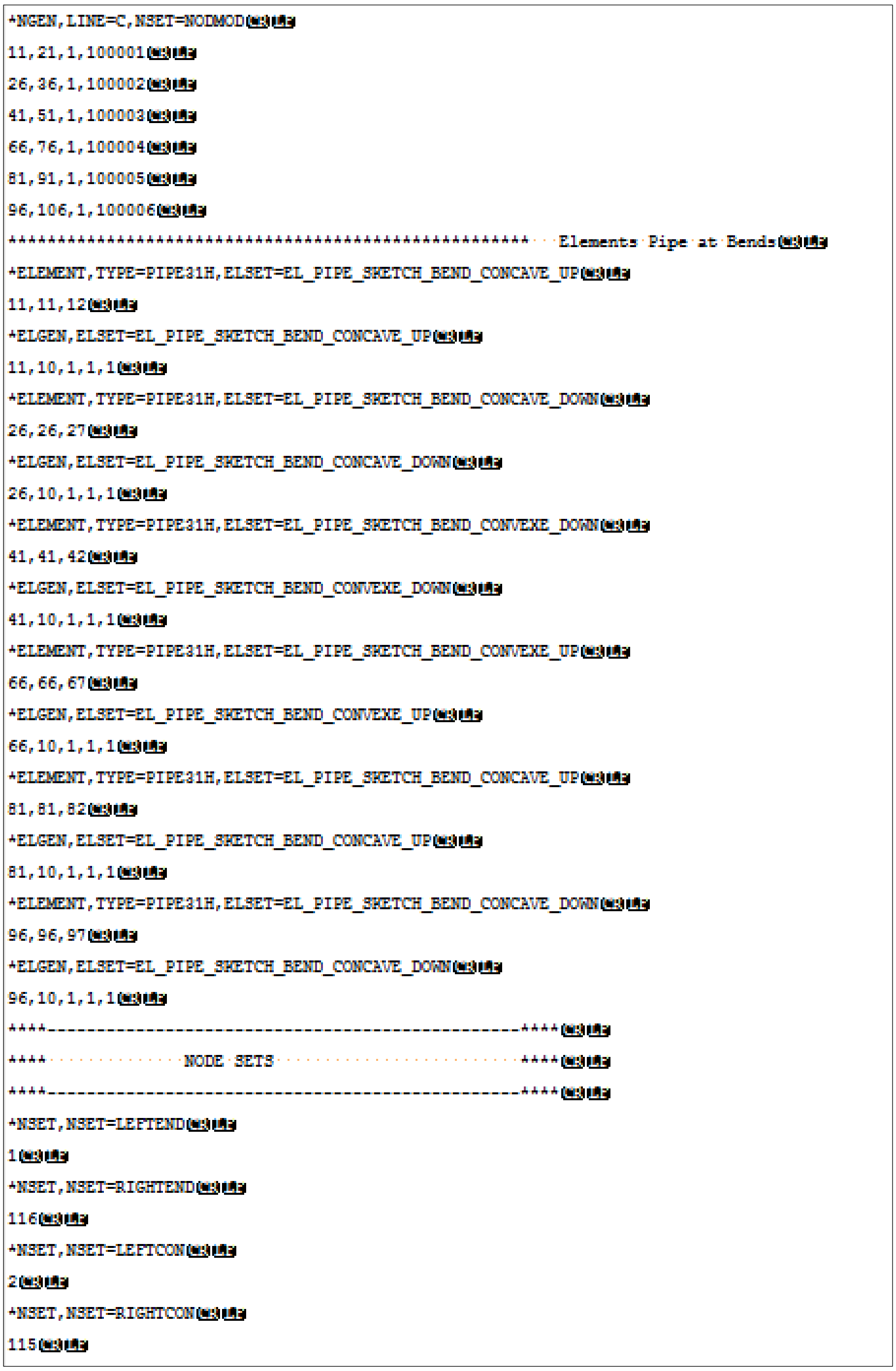
9. ASME, The American Society of Mechanical Engineers. Gas Transmission and Distribution Piping Systems. ASME B31.8-2010.
10. Offshore Standars OS-F101: “Submarine Pipeline Systems”. Det norske Veritas.
11. API 5L, Specification for Line Pipe, 44d Edition 2007
12. SAIPEM SA DOCUMENT, SHELL NIGERIA, WI Jumpers – Mechanical & Structural design report, Bonga Northwest, Phase II & STIFO

ATTACHMENT A – TYPICAL ABAQUS *.INP FILE

```
*HEADING
WIJ-04
***********************************************************************
****------------------------------------------------****
****             PIPE NODES      ****
****------------------------------------------------****
**
*RESTART ,  WRITE , OVERLAY
*NODE , NSET=NODMOD
1,0,0,0
3,0,0,0.281
6,0,0,1.181
11,0,0,6.8869
21,0.8481,0,7.735
26,2.0679,0,7.735
36,2.916,0,6.8869
41,2.916,0,1.0831
51,3.7641,0,0.235
66,26.3359,0,0.235
76,27.184,0,1.0831
81,27.184,0,6.8869
91,28.0321,0,7.735
96,29.2519,0,7.735
106,30.1,0,6.8869
111,30.1,0,1.008
114,30.1,0,0.108
116,30.1,0,-0.173
100001,0.8481,0,6.8869
100002,2.0679,0,6.8869
100003,3.7641,0,1.0831
100004,26.3359,0,1.0831
100005,28.0321,0,6.8869
100006,29.2519,0,6.8869
****************************************************** Jumper Straight Lines
*NGEN,NSET=NODMOD
1,3,1
3,6,1
6,11,1
21,26,1
36,41,1
51,66,1
76,81,1
91,96,1
106,111,1
111,114,1
114,116,1
```



```
*ELEMENT,TYPE-PIPE31H,ELSET-EL_PIPE_SKETCH_HUB_LEFT
1,1,2
*ELGEN,ELSET-EL_PIPE_SKETCH_HUB_LEFT
1,2,1,1,1
**
*ELEMENT,TYPE-PIPE31H,ELSET-EL_PIPE_SKETCH_PUP_LEFT
3,3,4
*ELGEN,ELSET-EL_PIPE_SKETCH_PUP_LEFT
3,3,1,1,1
**
*ELEMENT,TYPE-PIPE31H,ELSET-EL_PIPE_SKETCH_VERT_UP
6,6,7
*ELGEN,ELSET-EL_PIPE_SKETCH_VERT_UP
6,5,1,1,1
**
*ELEMENT,TYPE-PIPE31H,ELSET-EL_PIPE_SKETCH_HORIZ
21,21,22
*ELGEN,ELSET-EL_PIPE_SKETCH_HORIZ
21,5,1,1,1
**
*ELEMENT,TYPE-PIPE31H,ELSET-EL_PIPE_SKETCH_VERT_DOWN
36,36,37
*ELGEN,ELSET-EL_PIPE_SKETCH_VERT_DOWN
36,5,1,1,1
**
*ELEMENT,TYPE-PIPE31H,ELSET-EL_PIPE_SKETCH_HORIZ
51,51,52
*ELGEN,ELSET-EL_PIPE_SKETCH_HORIZ
51,15,1,1,1
**
*ELEMENT,TYPE-PIPE31H,ELSET-EL_PIPE_SKETCH_VERT_UP
76,76,77
*ELGEN,ELSET-EL_PIPE_SKETCH_VERT_UP
76,5,1,1,1
**
*ELEMENT,TYPE-PIPE31H,ELSET-EL_PIPE_SKETCH_HORIZ
91,91,92
*ELGEN,ELSET-EL_PIPE_SKETCH_HORIZ
91,5,1,1,1
**
*ELEMENT,TYPE-PIPE31H,ELSET-EL_PIPE_SKETCH_VERT_DOWN
106,106,107
*ELGEN,ELSET-EL_PIPE_SKETCH_VERT_DOWN
106,5,1,1,1
**
*ELEMENT,TYPE-PIPE31H,ELSET-EL_PIPE_SKETCH_PUP_RIGHT
111,111,112
*ELGEN,ELSET-EL_PIPE_SKETCH_PUP_RIGHT
111,3,1,1,1
**
*ELEMENT,TYPE-PIPE31H,ELSET-EL_PIPE_SKETCH_HUB_RIGHT
114,114,115
*ELGEN,ELSET-EL_PIPE_SKETCH_HUB_RIGHT
114,2,1,1,1
```



```
*NGEN,LINE=C,NSET=NODMOD
11,21,1,100001
26,36,1,100002
41,51,1,100003
66,76,1,100004
81,91,1,100005
96,106,1,100006
******************************************************   Elements Pipe at Bends
*ELEMENT,TYPE=PIPE31H,ELSET=EL_PIPE_SKETCH_BEND_CONCAVE_UP
11,11,12
*ELGEN,ELSET=EL_PIPE_SKETCH_BEND_CONCAVE_UP
11,10,1,1,1
*ELEMENT,TYPE=PIPE31H,ELSET=EL_PIPE_SKETCH_BEND_CONCAVE_DOWN
26,26,27
*ELGEN,ELSET=EL_PIPE_SKETCH_BEND_CONCAVE_DOWN
26,10,1,1,1
*ELEMENT,TYPE=PIPE31H,ELSET=EL_PIPE_SKETCH_BEND_CONVEXE_DOWN
41,41,42
*ELGEN,ELSET=EL_PIPE_SKETCH_BEND_CONVEXE_DOWN
41,10,1,1,1
*ELEMENT,TYPE=PIPE31H,ELSET=EL_PIPE_SKETCH_BEND_CONVEXE_UP
66,66,67
*ELGEN,ELSET=EL_PIPE_SKETCH_BEND_CONVEXE_UP
66,10,1,1,1
*ELEMENT,TYPE=PIPE31H,ELSET=EL_PIPE_SKETCH_BEND_CONCAVE_UP
81,81,82
*ELGEN,ELSET=EL_PIPE_SKETCH_BEND_CONCAVE_UP
81,10,1,1,1
*ELEMENT,TYPE=PIPE31H,ELSET=EL_PIPE_SKETCH_BEND_CONCAVE_DOWN
96,96,97
*ELGEN,ELSET=EL_PIPE_SKETCH_BEND_CONCAVE_DOWN
96,10,1,1,1
****-------------------------------------------------****
****              NODE SETS                          ****
****-------------------------------------------------****
*NSET,NSET=LEFTEND
1
*NSET,NSET=RIGHTEND
116
*NSET,NSET=LEFTCON
2
*NSET,NSET=RIGHTCON
115
```

```
****-------------------------------------------------****
****             PIPE SECTION      ****
****-------------------------------------------------****
*BEAM SECTION,SECTION=PIPE,ELSET=EL_PIPE_SKETCH_HUB_LEFT,MATERIAL=Connector_steel
0.16195,0.0206
 -1,0,0
32
*BEAM SECTION,SECTION=PIPE,ELSET=EL_PIPE_SKETCH_PUP_LEFT,MATERIAL=DNV450
0.16195,0.0206
 -1,0,0
32
*BEAM SECTION,SECTION=PIPE,ELSET=EL_PIPE_SKETCH_HUB_RIGHT,MATERIAL=Connector_steel
0.16195,0.0206
 1,0,0
32
*BEAM SECTION,SECTION=PIPE,ELSET=EL_PIPE_SKETCH_PUP_RIGHT,MATERIAL=DNV450
0.16195,0.0206
 1,0,0
32
*BEAM SECTION,SECTION=PIPE,ELSET=EL_PIPE_SKETCH_HORIZ,MATERIAL=DNV450
0.16195,0.0206
 0,0,-1
32
*BEAM SECTION,SECTION=PIPE,ELSET=EL_PIPE_SKETCH_VERT_UP,MATERIAL=DNV450
0.16195,0.0206
 -1,0,0
32
*BEAM SECTION,SECTION=PIPE,ELSET=EL_PIPE_SKETCH_VERT_DOWN,MATERIAL=DNV450
0.16195,0.0206
 -1,0,0
32
*BEAM SECTION,SECTION=PIPE,ELSET=EL_PIPE_SKETCH_BEND_CONCAVE_UP,MATERIAL=DNV450
0.16195,0.0206
 -1,0,0
32
*BEAM SECTION,SECTION=PIPE,ELSET=EL_PIPE_SKETCH_BEND_CONCAVE_DOWN,MATERIAL=DNV450
0.16195,0.0206
 0,0,1
32
*BEAM SECTION,SECTION=PIPE,ELSET=EL_PIPE_SKETCH_BEND_CONVEXE_DOWN,MATERIAL=DNV450
0.16195,0.0206
 1,0,0
32
*BEAM SECTION,SECTION=PIPE,ELSET=EL_PIPE_SKETCH_BEND_CONVEXE_UP,MATERIAL=DNV450
0.16195,0.0206
 0,0,1
32
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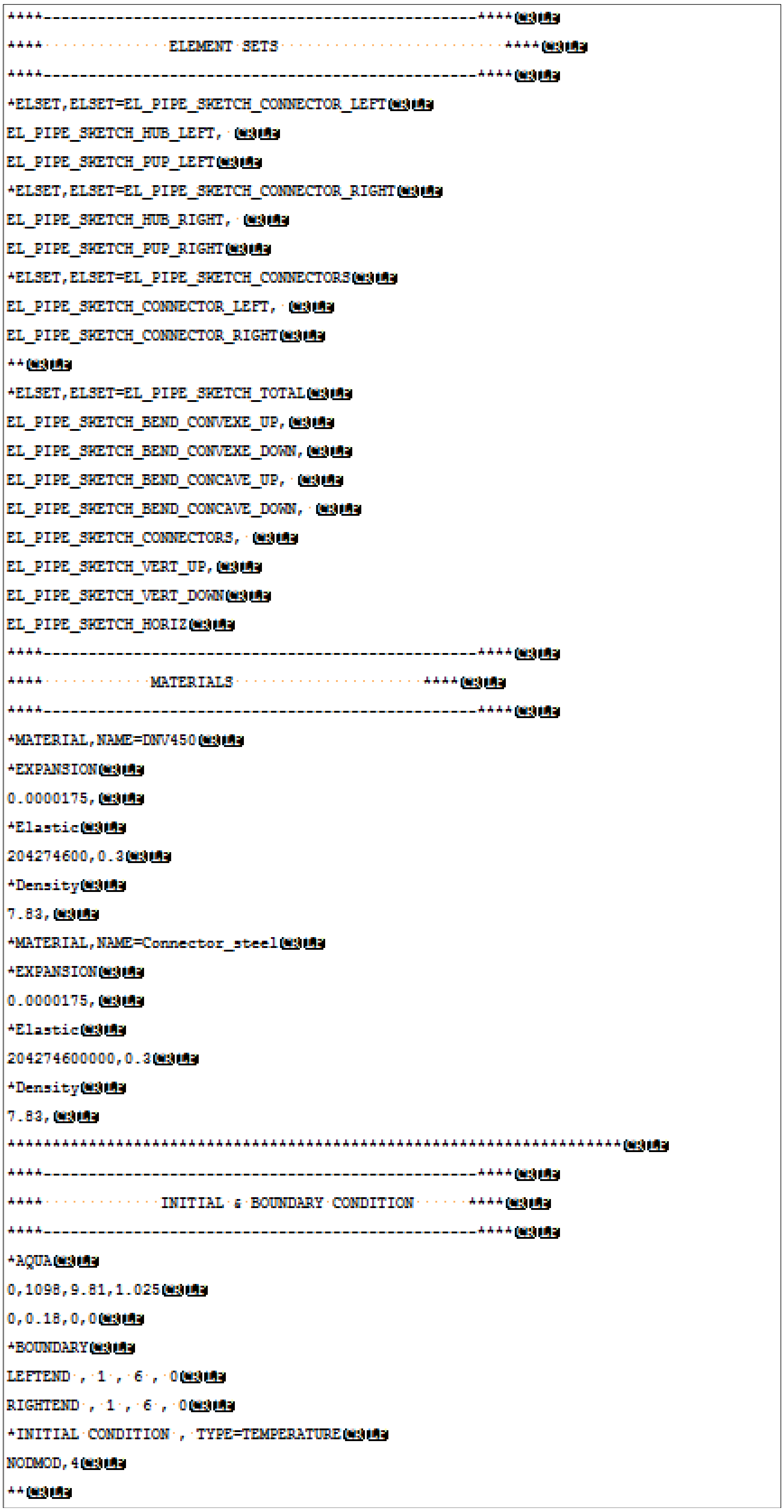
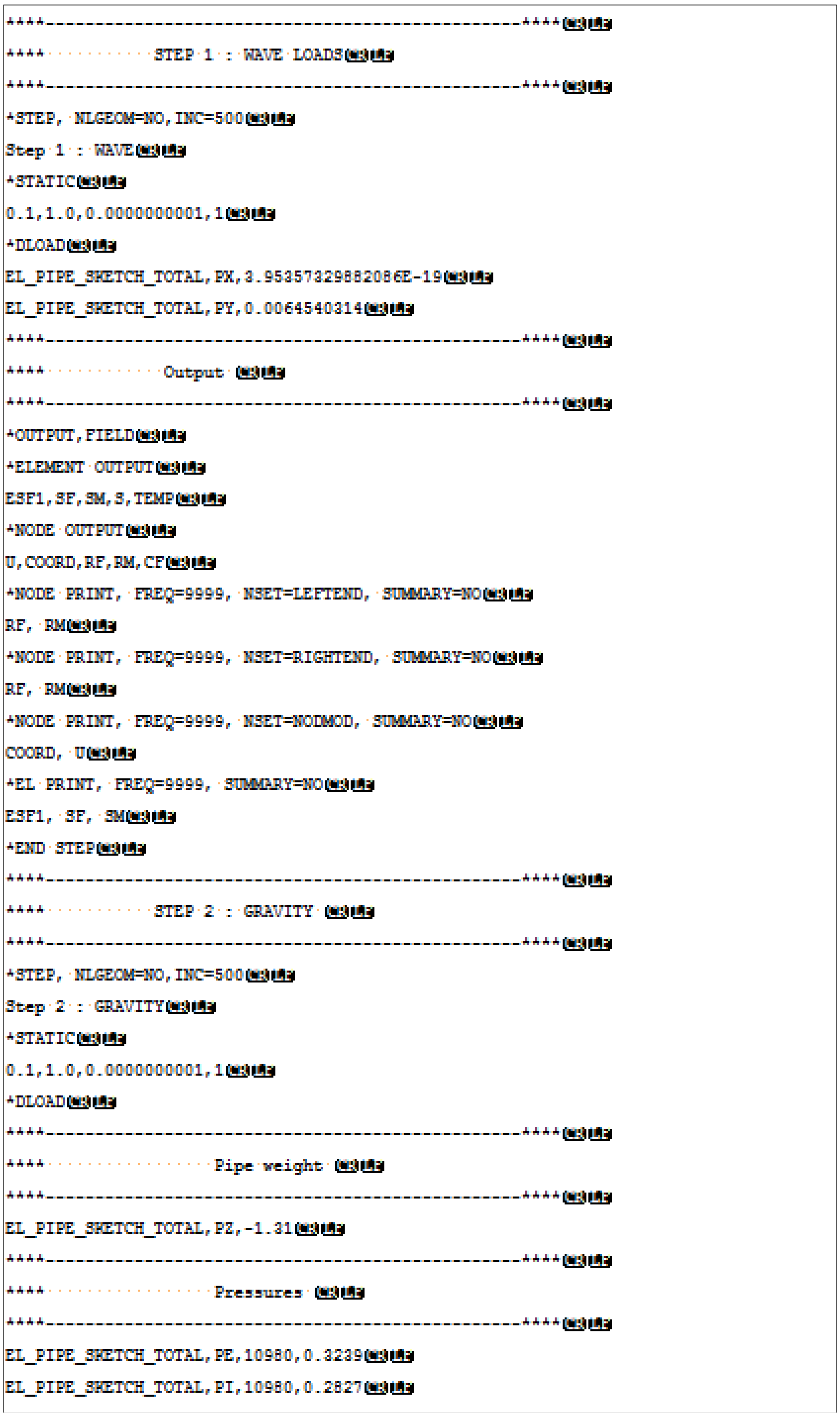


```
****------------------------------------------------****
****              ELEMENT SETS                         ****
****------------------------------------------------****
*ELSET,ELSET=EL_PIPE_SKETCH_CONNECTOR_LEFT
EL_PIPE_SKETCH_HUB_LEFT, 
EL_PIPE_SKETCH_PUP_LEFT
*ELSET,ELSET=EL_PIPE_SKETCH_CONNECTOR_RIGHT
EL_PIPE_SKETCH_HUB_RIGHT, 
EL_PIPE_SKETCH_PUP_RIGHT
*ELSET,ELSET=EL_PIPE_SKETCH_CONNECTORS
EL_PIPE_SKETCH_CONNECTOR_LEFT, 
EL_PIPE_SKETCH_CONNECTOR_RIGHT
**
*ELSET,ELSET=EL_PIPE_SKETCH_TOTAL
EL_PIPE_SKETCH_BEND_CONVEXE_UP,
EL_PIPE_SKETCH_BEND_CONVEXE_DOWN,
EL_PIPE_SKETCH_BEND_CONCAVE_UP, 
EL_PIPE_SKETCH_BEND_CONCAVE_DOWN, 
EL_PIPE_SKETCH_CONNECTORS, 
EL_PIPE_SKETCH_VERT_UP,
EL_PIPE_SKETCH_VERT_DOWN
EL_PIPE_SKETCH_HORIZ
****------------------------------------------------****
****            MATERIALS                     ****
****------------------------------------------------****
*MATERIAL,NAME=DNV450
*EXPANSION
0.0000175,
*Elastic
204274600,0.3
*Density
7.83,
*MATERIAL,NAME=Connector_steel
*EXPANSION
0.0000175,
*Elastic
204274600000,0.3
*Density
7.83,
********************************************************************
****------------------------------------------------****
****             INITIAL & BOUNDARY CONDITION      ****
****------------------------------------------------****
*AQUA
0,1098,9.81,1.025
0,0.18,0,0
*BOUNDARY
LEFTEND , 1 , 6 , 0
RIGHTEND , 1 , 6 , 0
*INITIAL CONDITION , TYPE=TEMPERATURE
NODMOD,4
**
```



```
****------------------------------------------------****
****           STEP 1 : WAVE LOADS
****------------------------------------------------****
*STEP, NLGEOM=NO,INC=500
Step 1 : WAVE
*STATIC
0.1,1.0,0.0000000001,1
*DLOAD
EL_PIPE_SKETCH_TOTAL,PX,3.95357329882086E-19
EL_PIPE_SKETCH_TOTAL,PY,0.0064540314
****------------------------------------------------****
****            Output 
****------------------------------------------------****
*OUTPUT,FIELD
*ELEMENT OUTPUT
ESF1,SF,SM,S,TEMP
*NODE OUTPUT
U,COORD,RF,RM,CF
*NODE PRINT, FREQ=9999, NSET=LEFTEND, SUMMARY=NO
RF, RM
*NODE PRINT, FREQ=9999, NSET=RIGHTEND, SUMMARY=NO
RF, RM
*NODE PRINT, FREQ=9999, NSET=NODMOD, SUMMARY=NO
COORD, U
*EL PRINT, FREQ=9999, SUMMARY=NO
ESF1, SF, SM
*END STEP
****------------------------------------------------****
****           STEP 2 : GRAVITY 
****------------------------------------------------****
*STEP, NLGEOM=NO,INC=500
Step 2 : GRAVITY
*STATIC
0.1,1.0,0.0000000001,1
*DLOAD
****------------------------------------------------****
****                 Pipe weight 
****------------------------------------------------****
EL_PIPE_SKETCH_TOTAL,PZ,-1.31
****------------------------------------------------****
****                 Pressures 
****------------------------------------------------****
EL_PIPE_SKETCH_TOTAL,PE,10980,0.3239
EL_PIPE_SKETCH_TOTAL,PI,10980,0.2827
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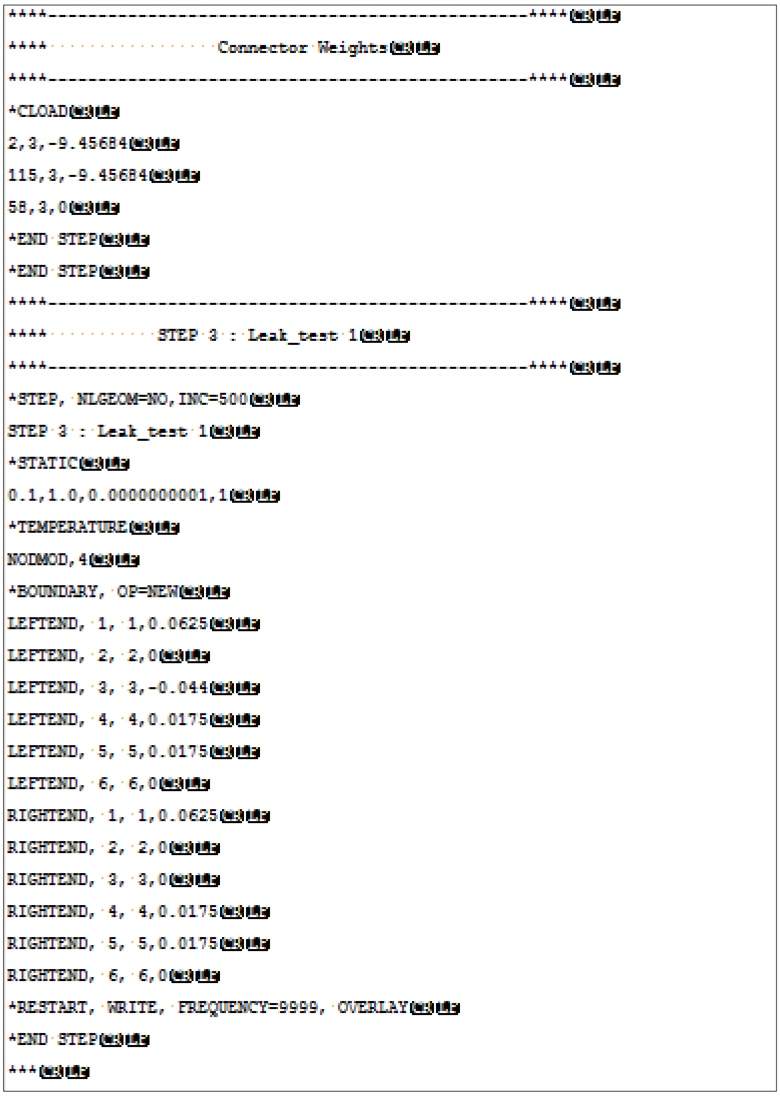

```
****------------------------------------------------****
****                 Connector Weights
****------------------------------------------------****
*CLOAD
2,3,-9.45684
115,3,-9.45684
58,3,0
*END STEP
*END STEP
****------------------------------------------------****
****           STEP 3 : Leak_test 1
****------------------------------------------------****
*STEP, NLGEOM=NO,INC=500
STEP 3 : Leak_test 1
*STATIC
0.1,1.0,0.0000000001,1
*TEMPERATURE
NODMOD,4
*BOUNDARY, OP=NEW
LEFTEND, 1, 1,0.0625
LEFTEND, 2, 2,0
LEFTEND, 3, 3,-0.044
LEFTEND, 4, 4,0.0175
LEFTEND, 5, 5,0.0175
LEFTEND, 6, 6,0
RIGHTEND, 1, 1,0.0625
RIGHTEND, 2, 2,0
RIGHTEND, 3, 3,0
RIGHTEND, 4, 4,0.0175
RIGHTEND, 5, 5,0.0175
RIGHTEND, 6, 6,0
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*END STEP
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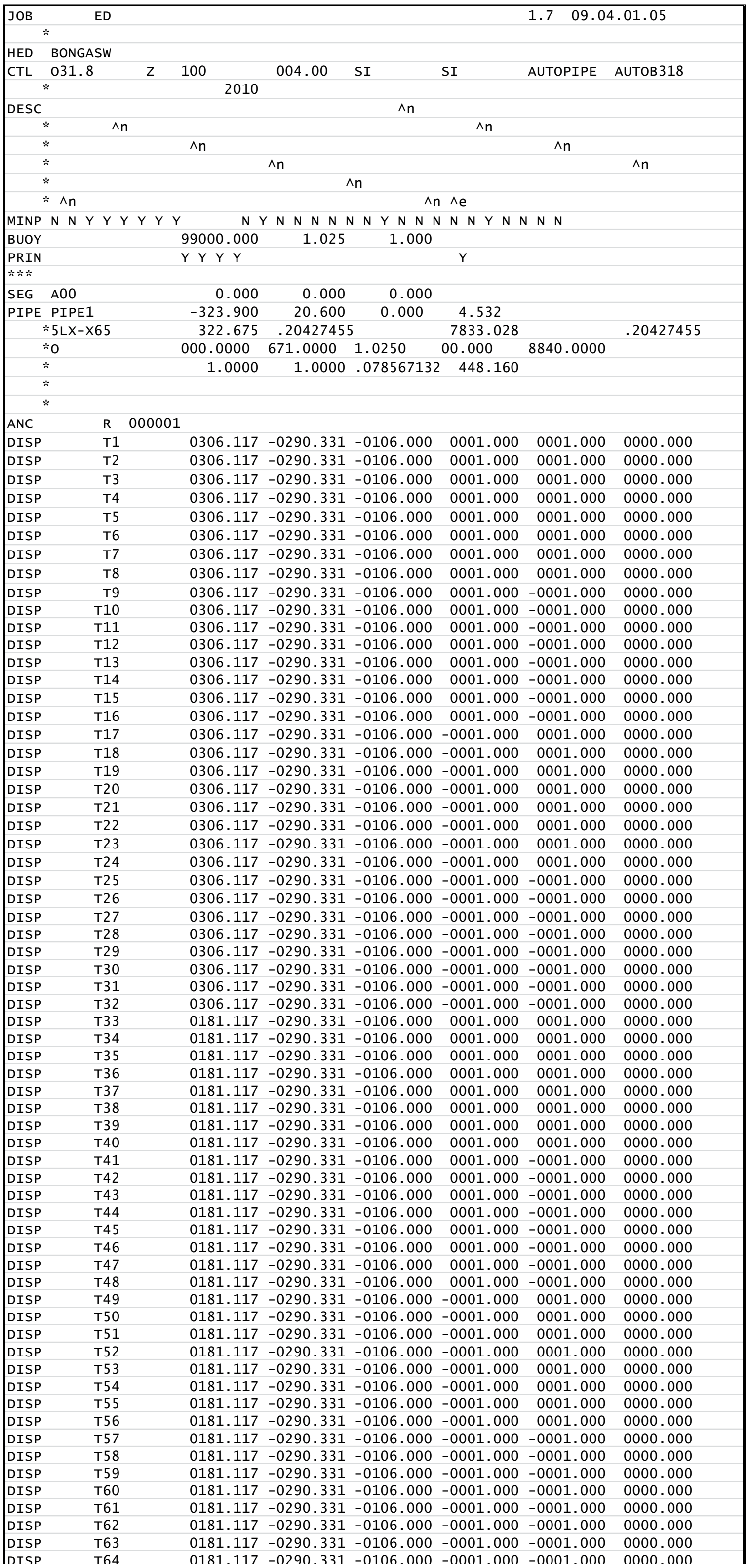
```

ATTACHMENT B – TYPICAL AUTOPIPE *.NTL FILE



```
JOB       ED                                                1.7  09.04.01.05
    *
HED  BONGASW
CTL  031.8      Z   100        004.00   SI        SI        AUTOPIPE  AUTOB318
    *                    2010
DESC                                         ^n
    *       ^n                                        ^n
    *                ^n                                        ^n
    *                         ^n                                        ^n
    *                                  ^n
    * ^n                                        ^n ^e
MINP N N Y Y Y Y Y Y       N Y N N N N N N Y N N N N N Y N N N N
BUOY                99000.000     1.025     1.000
PRIN                Y Y Y Y                         Y
***
SEG  A00                0.000     0.000     0.000
PIPE PIPE1           -323.900    20.600    0.000    4.532
    *5LX-X65          322.675  .20427455           7833.028            .20427455
    *O              000.0000  671.0000  1.0250    00.000    8840.0000
    *                  1.0000    1.0000 .078567132  448.160
    *
    *
ANC        R  000001
DISP       T1        0306.117 -0290.331 -0106.000  0001.000  0001.000  0000.000
DISP       T2        0306.117 -0290.331 -0106.000  0001.000  0001.000  0000.000
DISP       T3        0306.117 -0290.331 -0106.000  0001.000  0001.000  0000.000
DISP       T4        0306.117 -0290.331 -0106.000  0001.000  0001.000  0000.000
DISP       T5        0306.117 -0290.331 -0106.000  0001.000  0001.000  0000.000
DISP       T6        0306.117 -0290.331 -0106.000  0001.000  0001.000  0000.000
DISP       T7        0306.117 -0290.331 -0106.000  0001.000  0001.000  0000.000
DISP       T8        0306.117 -0290.331 -0106.000  0001.000  0001.000  0000.000
DISP       T9        0306.117 -0290.331 -0106.000  0001.000 -0001.000  0000.000
DISP      T10        0306.117 -0290.331 -0106.000  0001.000 -0001.000  0000.000
DISP      T11        0306.117 -0290.331 -0106.000  0001.000 -0001.000  0000.000
DISP      T12        0306.117 -0290.331 -0106.000  0001.000 -0001.000  0000.000
DISP      T13        0306.117 -0290.331 -0106.000  0001.000 -0001.000  0000.000
DISP      T14        0306.117 -0290.331 -0106.000  0001.000 -0001.000  0000.000
DISP      T15        0306.117 -0290.331 -0106.000  0001.000 -0001.000  0000.000
DISP      T16        0306.117 -0290.331 -0106.000  0001.000 -0001.000  0000.000
DISP      T17        0306.117 -0290.331 -0106.000 -0001.000  0001.000  0000.000
DISP      T18        0306.117 -0290.331 -0106.000 -0001.000  0001.000  0000.000
DISP      T19        0306.117 -0290.331 -0106.000 -0001.000  0001.000  0000.000
DISP      T20        0306.117 -0290.331 -0106.000 -0001.000  0001.000  0000.000
DISP      T21        0306.117 -0290.331 -0106.000 -0001.000  0001.000  0000.000
DISP      T22        0306.117 -0290.331 -0106.000 -0001.000  0001.000  0000.000
DISP      T23        0306.117 -0290.331 -0106.000 -0001.000  0001.000  0000.000
DISP      T24        0306.117 -0290.331 -0106.000 -0001.000  0001.000  0000.000
DISP      T25        0306.117 -0290.331 -0106.000 -0001.000 -0001.000  0000.000
DISP      T26        0306.117 -0290.331 -0106.000 -0001.000 -0001.000  0000.000
DISP      T27        0306.117 -0290.331 -0106.000 -0001.000 -0001.000  0000.000
DISP      T28        0306.117 -0290.331 -0106.000 -0001.000 -0001.000  0000.000
DISP      T29        0306.117 -0290.331 -0106.000 -0001.000 -0001.000  0000.000
DISP      T30        0306.117 -0290.331 -0106.000 -0001.000 -0001.000  0000.000
DISP      T31        0306.117 -0290.331 -0106.000 -0001.000 -0001.000  0000.000
DISP      T32        0306.117 -0290.331 -0106.000 -0001.000 -0001.000  0000.000
DISP      T33        0181.117 -0290.331 -0106.000  0001.000  0001.000  0000.000
DISP      T34        0181.117 -0290.331 -0106.000  0001.000  0001.000  0000.000
DISP      T35        0181.117 -0290.331 -0106.000  0001.000  0001.000  0000.000
DISP      T36        0181.117 -0290.331 -0106.000  0001.000  0001.000  0000.000
DISP      T37        0181.117 -0290.331 -0106.000  0001.000  0001.000  0000.000
DISP      T38        0181.117 -0290.331 -0106.000  0001.000  0001.000  0000.000
DISP      T39        0181.117 -0290.331 -0106.000  0001.000  0001.000  0000.000
DISP      T40        0181.117 -0290.331 -0106.000  0001.000  0001.000  0000.000
DISP      T41        0181.117 -0290.331 -0106.000  0001.000 -0001.000  0000.000
DISP      T42        0181.117 -0290.331 -0106.000  0001.000 -0001.000  0000.000
DISP      T43        0181.117 -0290.331 -0106.000  0001.000 -0001.000  0000.000
DISP      T44        0181.117 -0290.331 -0106.000  0001.000 -0001.000  0000.000
DISP      T45        0181.117 -0290.331 -0106.000  0001.000 -0001.000  0000.000
DISP      T46        0181.117 -0290.331 -0106.000  0001.000 -0001.000  0000.000
DISP      T47        0181.117 -0290.331 -0106.000  0001.000 -0001.000  0000.000
DISP      T48        0181.117 -0290.331 -0106.000  0001.000 -0001.000  0000.000
DISP      T49        0181.117 -0290.331 -0106.000 -0001.000  0001.000  0000.000
DISP      T50        0181.117 -0290.331 -0106.000 -0001.000  0001.000  0000.000
DISP      T51        0181.117 -0290.331 -0106.000 -0001.000  0001.000  0000.000
DISP      T52        0181.117 -0290.331 -0106.000 -0001.000  0001.000  0000.000
DISP      T53        0181.117 -0290.331 -0106.000 -0001.000  0001.000  0000.000
DISP      T54        0181.117 -0290.331 -0106.000 -0001.000  0001.000  0000.000
DISP      T55        0181.117 -0290.331 -0106.000 -0001.000  0001.000  0000.000
DISP      T56        0181.117 -0290.331 -0106.000 -0001.000  0001.000  0000.000
DISP      T57        0181.117 -0290.331 -0106.000 -0001.000 -0001.000  0000.000
DISP      T58        0181.117 -0290.331 -0106.000 -0001.000 -0001.000  0000.000
DISP      T59        0181.117 -0290.331 -0106.000 -0001.000 -0001.000  0000.000
DISP      T60        0181.117 -0290.331 -0106.000 -0001.000 -0001.000  0000.000
DISP      T61        0181.117 -0290.331 -0106.000 -0001.000 -0001.000  0000.000
DISP      T62        0181.117 -0290.331 -0106.000 -0001.000 -0001.000  0000.000
DISP      T63        0181.117 -0290.331 -0106.000 -0001.000 -0001.000  0000.000
DISP      T64        0181.117 -0290.331 -0106.000 -0001.000 -0001.000  0000.000
```

```
OPER A00   1         26.500        016.620        A              A
    *            A
OPER A00   2         26.500        016.620        A              A
    *            A
OPER A00   3         26.500        016.620        A              A
    *            A
OPER A00   4         26.500        016.620        A              A
    *            A
OPER A00   5         26.500        016.620        A              A
    *            A
OPER A00   6         26.500        016.620        A              A
    *            A
OPER A00   7         26.500        016.620        A              A
    *            A
OPER A00   8         26.500        016.620        A              A
    *            A
OPER A00   9         26.500        016.620        A              A
    *            A
OPER A00  10         26.500        016.620        A              A
    *            A
OPER A00  11         26.500        016.620        A              A
    *            A
OPER A00  12         26.500        016.620        A              A
    *            A
OPER A00  13         26.500        016.620        A              A
    *            A
OPER A00  14         26.500        016.620        A              A
    *            A
OPER A00  15         26.500        016.620        A              A
    *            A
OPER A00  16         26.500        016.620        A              A
    *            A
OPER A00  17         26.500        016.620        A              A
    *            A
OPER A00  18         26.500        016.620        A              A
    *            A
OPER A00  19         26.500        016.620        A              A
    *            A
OPER A00  20         26.500        016.620        A              A
    *            A
OPER A00  21         26.500        016.620        A              A
    *            A
OPER A00  22         26.500        016.620        A              A
    *            A
OPER A00  23         26.500        016.620        A              A
    *            A
OPER A00  24         26.500        016.620        A              A
    *            A
OPER A00  25         26.500        016.620        A              A
    *            A
OPER A00  26         26.500        016.620        A              A
    *            A
OPER A00  27         26.500        016.620        A              A
    *            A
OPER A00  28         26.500        016.620        A              A
    *            A
OPER A00  29         26.500        016.620        A              A
    *            A
OPER A00  30         26.500        016.620        A              A
    *            A
OPER A00  31         26.500        016.620        A              A
    *            A
OPER A00  32         26.500        016.620        A              A
    *            A
OPER A00  33         26.500        016.620        A              A
    *            A
OPER A00  34         26.500        016.620        A              A
    *            A
OPER A00  35         26.500        016.620        A              A
    *            A
OPER A00  36         26.500        016.620        A              A
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OPER A00  37         26.500        016.620        A              A
    *            A
OPER A00  38         26.500        016.620        A              A
    *            A
OPER A00  39         26.500        016.620        A              A
    *            A
OPER A00  40         26.500        016.620        A              A
    *            A
OPER A00  41         26.500        016.620        A              A
    *            A
OPER A00  42         26.500        016.620        A              A
    *            A
OPER A00  43         26.500        016.620        A              A
    *            A
OPER A00  44         26.500        016.620        A              A
    *            A
OPER A00  45         26.500        016.620        A              A
    *            A
OPER A00  46         26.500        016.620        A              A
    *            A
OPER A00  47         26.500        016.620        A              A
    *            A
OPER A00  48         26.500        016.620        A              A
    *            A
OPER A00  49         26.500        016.620        A              A
    *            A
OPER A00  50         26.500        016.620        A              A
    *            A
OPER A00  51         26.500        016.620        A              A
    *            A
OPER A00  52         26.500        016.620        A              A
    *            A
OPER A00  53         26.500        016.620        A              A
    *            A
OPER A00  54         26.500        016.620        A              A
    *            A
OPER A00  55         26.500        016.620        A              A
    *            A
OPER A00  56         26.500        016.620        A              A
    *            A
OPER A00  57         26.500        016.620        A              A
    *            A
OPER A00  58         26.500        016.620        A              A
    *            A
OPER A00  59         26.500        016.620        A              A
    *            A
OPER A00  60         26.500        016.620        A              A
    *            A
OPER A00  61         26.500        016.620        A              A
    *            A
OPER A00  62         26.500        016.620        A              A
    *            A
OPER A00  63         26.500        016.620        A              A
    *            A
OPER A00  64         26.500        016.620        A              A
    *            A
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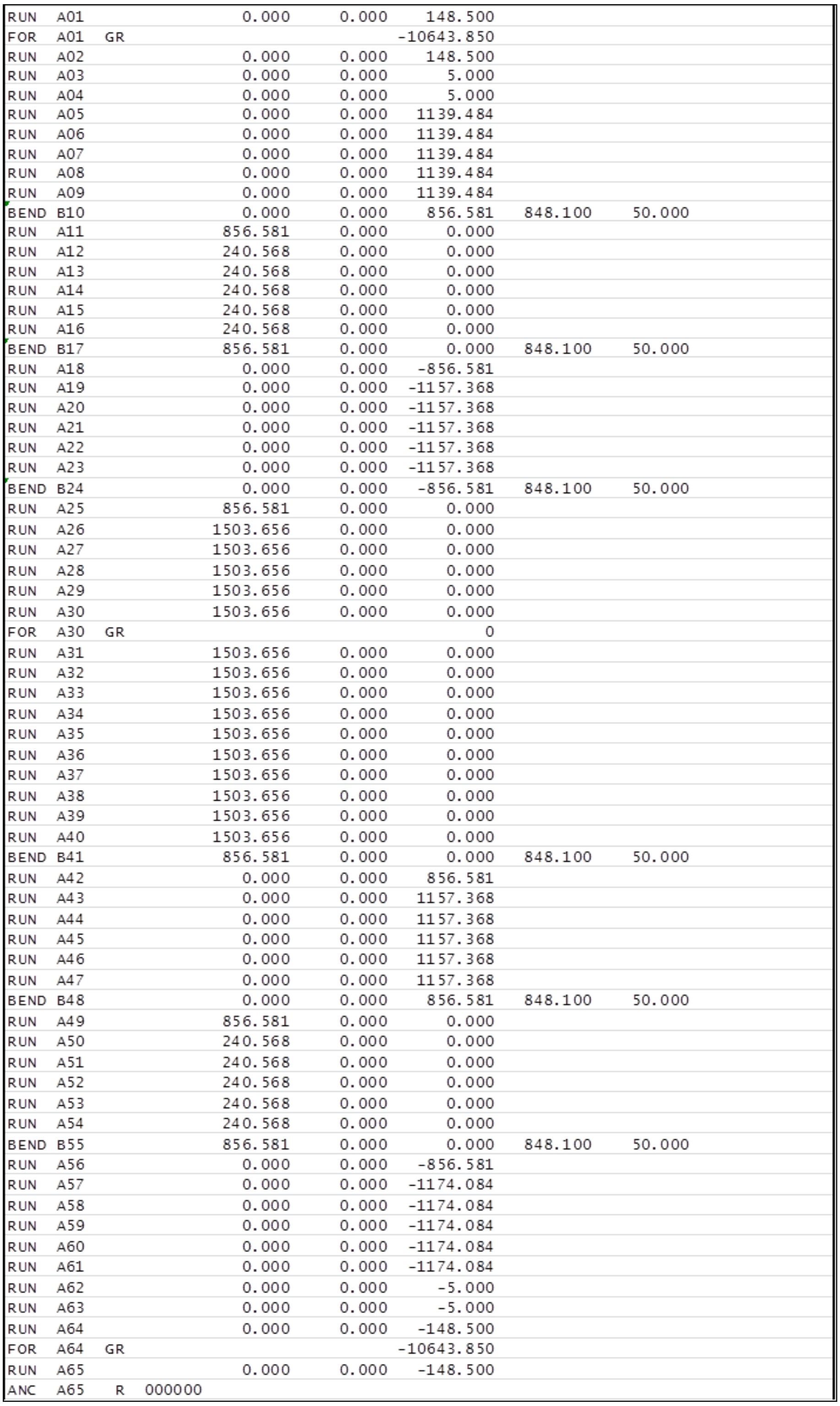

```
RUN  A01           0.000    0.000    148.500
FOR  A01  GR                      -10643.850
RUN  A02           0.000    0.000    148.500
RUN  A03           0.000    0.000      5.000
RUN  A04           0.000    0.000      5.000
RUN  A05           0.000    0.000   1139.484
RUN  A06           0.000    0.000   1139.484
RUN  A07           0.000    0.000   1139.484
RUN  A08           0.000    0.000   1139.484
RUN  A09           0.000    0.000   1139.484
BEND B10           0.000    0.000    856.581   848.100    50.000
RUN  A11         856.581    0.000      0.000
RUN  A12         240.568    0.000      0.000
RUN  A13         240.568    0.000      0.000
RUN  A14         240.568    0.000      0.000
RUN  A15         240.568    0.000      0.000
RUN  A16         240.568    0.000      0.000
BEND B17         856.581    0.000      0.000   848.100    50.000
RUN  A18           0.000    0.000   -856.581
RUN  A19           0.000    0.000  -1157.368
RUN  A20           0.000    0.000  -1157.368
RUN  A21           0.000    0.000  -1157.368
RUN  A22           0.000    0.000  -1157.368
RUN  A23           0.000    0.000  -1157.368
BEND B24           0.000    0.000   -856.581   848.100    50.000
RUN  A25         856.581    0.000      0.000
RUN  A26        1503.656    0.000      0.000
RUN  A27        1503.656    0.000      0.000
RUN  A28        1503.656    0.000      0.000
RUN  A29        1503.656    0.000      0.000
RUN  A30        1503.656    0.000      0.000
FOR  A30  GR                               0
RUN  A31        1503.656    0.000      0.000
RUN  A32        1503.656    0.000      0.000
RUN  A33        1503.656    0.000      0.000
RUN  A34        1503.656    0.000      0.000
RUN  A35        1503.656    0.000      0.000
RUN  A36        1503.656    0.000      0.000
RUN  A37        1503.656    0.000      0.000
RUN  A38        1503.656    0.000      0.000
RUN  A39        1503.656    0.000      0.000
RUN  A40        1503.656    0.000      0.000
BEND B41         856.581    0.000      0.000   848.100    50.000
RUN  A42           0.000    0.000    856.581
RUN  A43           0.000    0.000   1157.368
RUN  A44           0.000    0.000   1157.368
RUN  A45           0.000    0.000   1157.368
RUN  A46           0.000    0.000   1157.368
RUN  A47           0.000    0.000   1157.368
BEND B48           0.000    0.000    856.581   848.100    50.000
RUN  A49         856.581    0.000      0.000
RUN  A50         240.568    0.000      0.000
RUN  A51         240.568    0.000      0.000
RUN  A52         240.568    0.000      0.000
RUN  A53         240.568    0.000      0.000
RUN  A54         240.568    0.000      0.000
BEND B55         856.581    0.000      0.000   848.100    50.000
RUN  A56           0.000    0.000   -856.581
RUN  A57           0.000    0.000  -1174.084
RUN  A58           0.000    0.000  -1174.084
RUN  A59           0.000    0.000  -1174.084
RUN  A60           0.000    0.000  -1174.084
RUN  A61           0.000    0.000  -1174.084
RUN  A62           0.000    0.000     -5.000
RUN  A63           0.000    0.000     -5.000
RUN  A64           0.000    0.000   -148.500
FOR  A64  GR                      -10643.850
RUN  A65           0.000    0.000   -148.500
ANC  A65   R   000000
```

```
DISP       T1       -0228.130 -0274.835 -0100.000  0001.000  0001.000  0000.000
DISP       T2       -0228.130 -0274.835 -0100.000  0001.000 -0001.000  0000.000
DISP       T3       -0228.130 -0274.835 -0100.000 -0001.000  0001.000  0000.000
DISP       T4       -0228.130 -0274.835 -0100.000 -0001.000 -0001.000  0000.000
DISP       T5       -0353.130 -0274.835 -0100.000  0001.000  0001.000  0000.000
DISP       T6       -0353.130 -0274.835 -0100.000  0001.000 -0001.000  0000.000
DISP       T7       -0353.130 -0274.835 -0100.000 -0001.000  0001.000  0000.000
DISP       T8       -0353.130 -0274.835 -0100.000 -0001.000 -0001.000  0000.000
DISP       T9       -0228.130 -0274.835 -0100.000  0001.000  0001.000  0000.000
DISP      T10       -0228.130 -0274.835 -0100.000  0001.000 -0001.000  0000.000
DISP      T11       -0228.130 -0274.835 -0100.000 -0001.000  0001.000  0000.000
DISP      T12       -0228.130 -0274.835 -0100.000 -0001.000 -0001.000  0000.000
DISP      T13       -0353.130 -0274.835 -0100.000  0001.000  0001.000  0000.000
DISP      T14       -0353.130 -0274.835 -0100.000  0001.000 -0001.000  0000.000
DISP      T15       -0353.130 -0274.835 -0100.000 -0001.000  0001.000  0000.000
DISP      T16       -0353.130 -0274.835 -0100.000 -0001.000 -0001.000  0000.000
DISP      T17       -0228.130 -0274.835 -0100.000  0001.000  0001.000  0000.000
DISP      T18       -0228.130 -0274.835 -0100.000  0001.000 -0001.000  0000.000
DISP      T19       -0228.130 -0274.835 -0100.000 -0001.000  0001.000  0000.000
DISP      T20       -0228.130 -0274.835 -0100.000 -0001.000 -0001.000  0000.000
DISP      T21       -0353.130 -0274.835 -0100.000  0001.000  0001.000  0000.000
DISP      T22       -0353.130 -0274.835 -0100.000  0001.000 -0001.000  0000.000
DISP      T23       -0353.130 -0274.835 -0100.000 -0001.000  0001.000  0000.000
DISP      T24       -0353.130 -0274.835 -0100.000 -0001.000 -0001.000  0000.000
DISP      T25       -0228.130 -0274.835 -0100.000  0001.000  0001.000  0000.000
DISP      T26       -0228.130 -0274.835 -0100.000  0001.000 -0001.000  0000.000
DISP      T27       -0228.130 -0274.835 -0100.000 -0001.000  0001.000  0000.000
DISP      T28       -0228.130 -0274.835 -0100.000 -0001.000 -0001.000  0000.000
DISP      T29       -0353.130 -0274.835 -0100.000  0001.000  0001.000  0000.000
DISP      T30       -0353.130 -0274.835 -0100.000  0001.000 -0001.000  0000.000
DISP      T31       -0353.130 -0274.835 -0100.000 -0001.000  0001.000  0000.000
DISP      T32       -0353.130 -0274.835 -0100.000 -0001.000 -0001.000  0000.000
DISP      T33       -0228.130 -0274.835 -0100.000  0001.000  0001.000  0000.000
DISP      T34       -0228.130 -0274.835 -0100.000  0001.000 -0001.000  0000.000
DISP      T35       -0228.130 -0274.835 -0100.000 -0001.000  0001.000  0000.000
DISP      T36       -0228.130 -0274.835 -0100.000 -0001.000 -0001.000  0000.000
DISP      T37       -0353.130 -0274.835 -0100.000  0001.000  0001.000  0000.000
DISP      T38       -0353.130 -0274.835 -0100.000  0001.000 -0001.000  0000.000
DISP      T39       -0353.130 -0274.835 -0100.000 -0001.000  0001.000  0000.000
DISP      T40       -0353.130 -0274.835 -0100.000 -0001.000 -0001.000  0000.000
DISP      T41       -0228.130 -0274.835 -0100.000  0001.000  0001.000  0000.000
DISP      T42       -0228.130 -0274.835 -0100.000  0001.000 -0001.000  0000.000
DISP      T43       -0228.130 -0274.835 -0100.000 -0001.000  0001.000  0000.000
DISP      T44       -0228.130 -0274.835 -0100.000 -0001.000 -0001.000  0000.000
DISP      T45       -0353.130 -0274.835 -0100.000  0001.000  0001.000  0000.000
DISP      T46       -0353.130 -0274.835 -0100.000  0001.000 -0001.000  0000.000
DISP      T47       -0353.130 -0274.835 -0100.000 -0001.000  0001.000  0000.000
DISP      T48       -0353.130 -0274.835 -0100.000 -0001.000 -0001.000  0000.000
DISP      T49       -0228.130 -0274.835 -0100.000  0001.000  0001.000  0000.000
DISP      T50       -0228.130 -0274.835 -0100.000  0001.000 -0001.000  0000.000
DISP      T51       -0228.130 -0274.835 -0100.000 -0001.000  0001.000  0000.000
DISP      T52       -0228.130 -0274.835 -0100.000 -0001.000 -0001.000  0000.000
DISP      T53       -0353.130 -0274.835 -0100.000  0001.000  0001.000  0000.000
DISP      T54       -0353.130 -0274.835 -0100.000  0001.000 -0001.000  0000.000
DISP      T55       -0353.130 -0274.835 -0100.000 -0001.000  0001.000  0000.000
DISP      T56       -0353.130 -0274.835 -0100.000 -0001.000 -0001.000  0000.000
DISP      T57       -0228.130 -0274.835 -0100.000  0001.000  0001.000  0000.000
DISP      T58       -0228.130 -0274.835 -0100.000  0001.000 -0001.000  0000.000
DISP      T59       -0228.130 -0274.835 -0100.000 -0001.000  0001.000  0000.000
DISP      T60       -0228.130 -0274.835 -0100.000 -0001.000 -0001.000  0000.000
DISP      T61       -0353.130 -0274.835 -0100.000  0001.000  0001.000  0000.000
DISP      T62       -0353.130 -0274.835 -0100.000  0001.000 -0001.000  0000.000
DISP      T63       -0353.130 -0274.835 -0100.000 -0001.000  0001.000  0000.000
DISP      T64       -0353.130 -0274.835 -0100.000 -0001.000 -0001.000  0000.000
***
***  ----RIGID OPTIONS DATA----
RSTF               1000.000
RIGD A00                N    Y
RIGD A01                N    Y
RIGD A63                N    Y
RIGD A64                N    Y
***
DIST A00    U1   A65  000.000   006.454             000.000   006.454
***
MODE   12    0 Y       33.000    0       N N N
SOLV Y    STAT     1          N         Y
    *Load Set No. 1
    *Y    N        0        30    0.025    44.482     0.100     1.000  Y Y Y N 0
    *GR,,U1,,T1,,T2,,T3,,T4,,T5,,T6,,T7,,T8,,T9,,T10,,T11,,
    *T12,,T13,,T14,,T15,,T16,,T17,,T18,,T19,,T20,,T21,,
    *T22,,T23,,T24,,T25,,T26,,T27,,T28,,T29,,T30,,T31,,
    *T32,,T33,,T34,,T35,,T36,,T37,,T38,,T39,,T40,,T41,,
    *T42,,T43,,T44,,T45,,T46,,T47,,T48,,T49,,T50,,T51,,
    *T52,,T53,,T54,,T55,,T56,,T57,,T58,,T59,,T60,,T61,,
    *T62,,T63,,T64,,P1
***   END OF FILE
```

ATTACHMENT C – BONGA NORTHWEST JUMPER LAYOUT CONFIGURATIONS

This appendix presents the jumper layouts of the 12” Water Injection Jumper Bonga North West project (see part 4.1 of this report)

- Nominal (NOM) – 25.8m hub-hub length
- Far Far (FF) – 30.1m hub-hub length
- Far Far Worst Angle (FFWA) – 26.6m hub-hub length
- Near Near (NN) – 21.5m hub-hub length
- Near Near Worst Angle (NNWA) – 25.7m hub-hub length

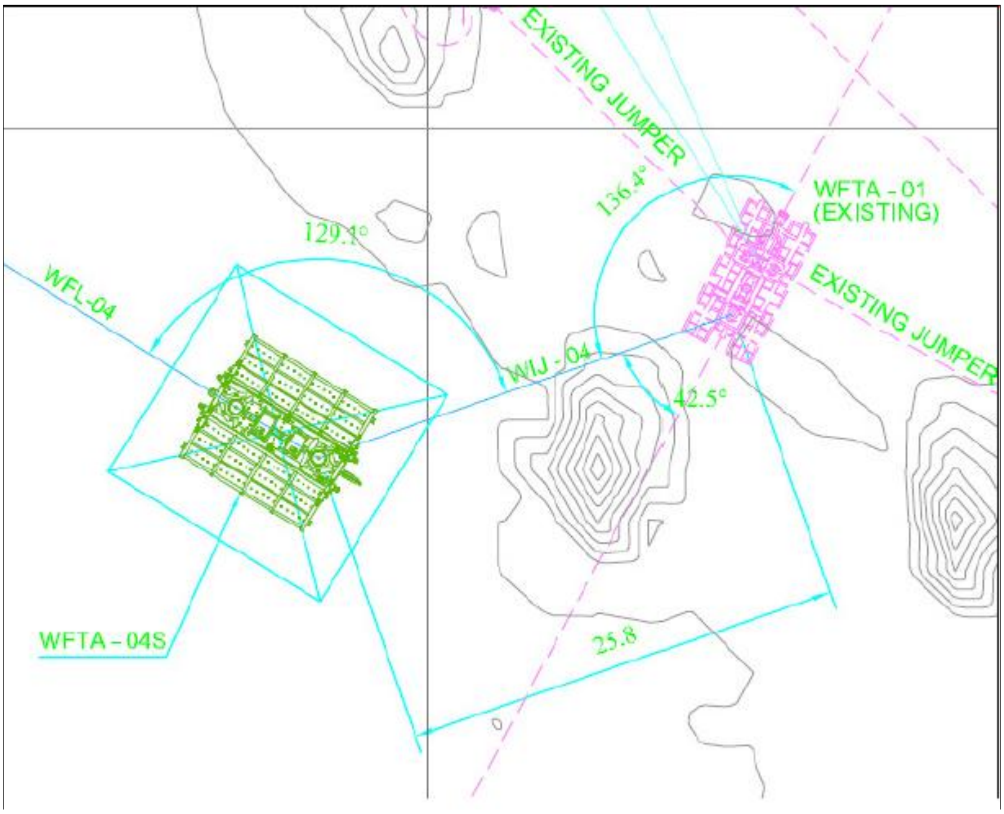

Figure 56. Nominal Configuration

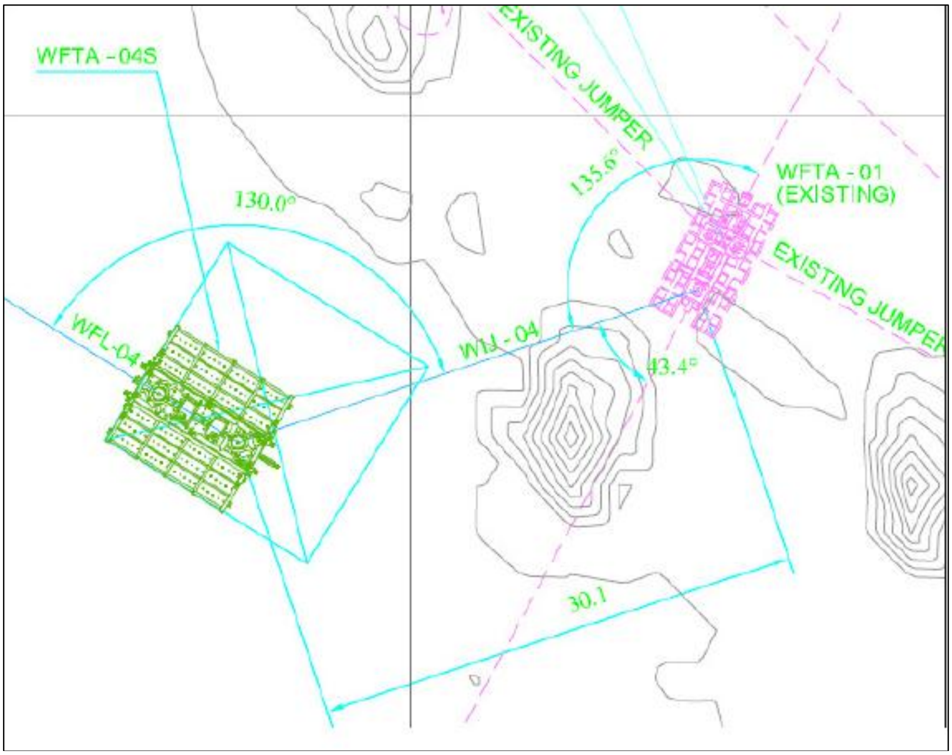

Figure 57. Far Far Configuration

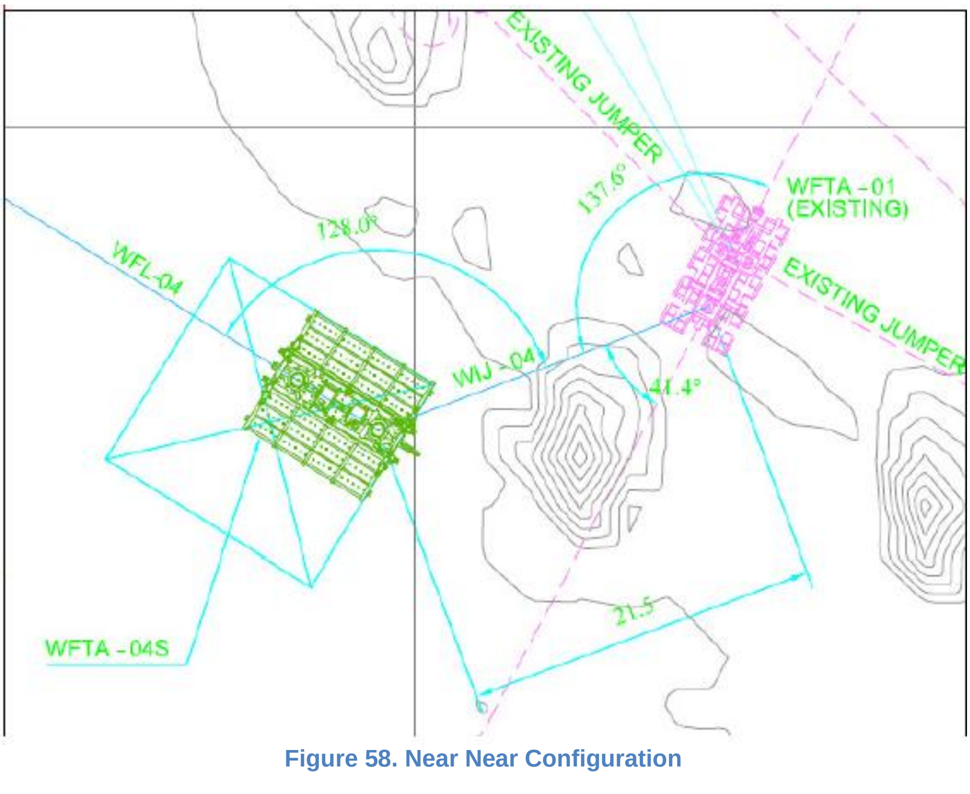

Figure 58. Near Near Configuration

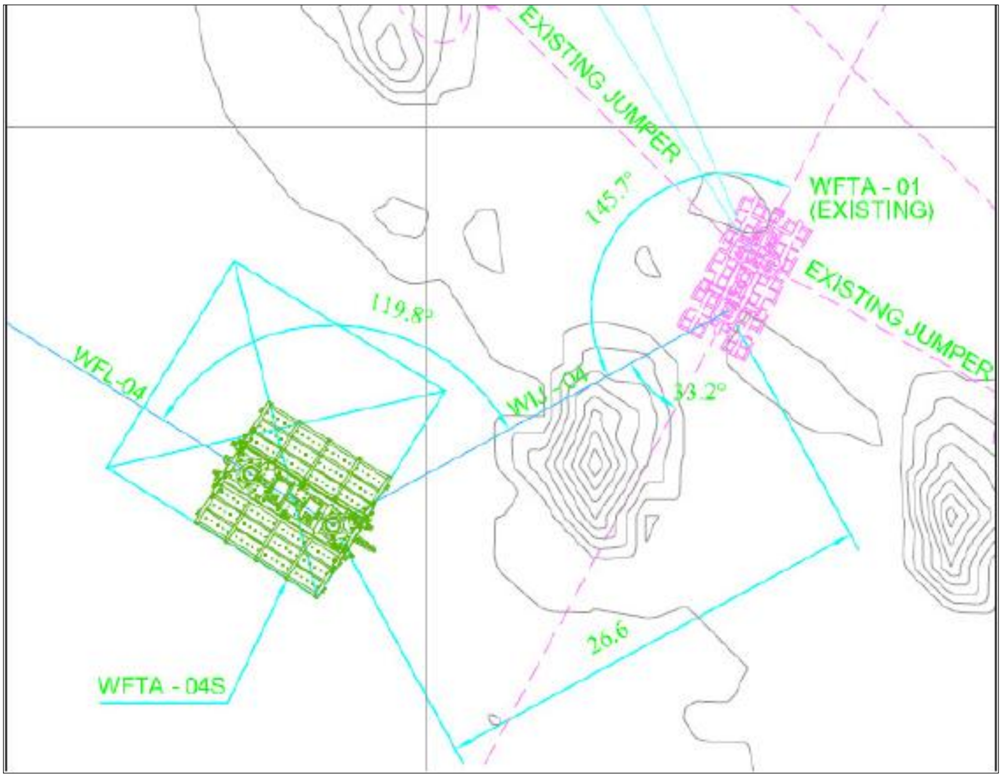

Figure 59. FFWA Configuration

Figure 60. NNWA Configuration