FABRICATION OF COMPOSITE BALL SOCKET PIPELINE JACKET FOR SUBSEA FLOWLINES PROTECTION SYSTEMS

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MECHANICAL ENGINEERING

UNIVERSITI TEKNOLOGI PETRONAS

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Fabrication of Composite Ball Socket Pipeline Jacket For Subsea Flowlines Protection Systems

By

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Dissertation submitted in partial fulfilment of

as a Requirement for the

Bachelor of Engineering (Hons)

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CERTIFICATION OF APPROVAL

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A project dissertation submitter to the
Mechanical Engineering Programme
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In partial fulfilment of the requirement for the
BACHELOR OF ENGINEERING (Hons)
(MECHANICAL)

Approved by,

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertake or done by unspecified sources or persons.

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ABSTRACT

Ball Socket Pipeline Jacket (BSPJ) is a protective system for onshore or offshore pipelines to shield cables from abrasion, corrosion, and impact while providing a system with custom additional submerged weight that suit the bottom stabilization of offshore flow-lines taking into account that BSPJ could be a sophisticated bending-restrictor system. This study shows the prototyping procedures and the robust testing of the full-scale prototype through physical failure test and software simulation of the BSPJ under critical pressure limit. Simulation of the BSPJ is analysed under environmental and operational conditions on BSPJ viscoelastic limit in accordance with DNV-RP-F109. Their reliability growth, accelerated life and robust design were determined to further improve the design for commercialisation. The ball socket design shows that it could withstand a high compression load through buckling test. New design of the BSPJ definitively reduce total volume for each part and ease assembly thus improving the capital and operating costs.

ACKNOWLEDGEMENTS

Firstly, all praises to the Almighty Allah swt. for His blessings and His guidance without which I could not have done my project smoothly. Greatest appreciation to my beloved family especially to my parents, Nasrudin bin Johari and Zarina binti Hashim, who have been raising me and supporting me in everything that I do as well as giving me the motivation to continue whenever I needed.

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CHAPTER 1

INTRODUCTION

1.1 Background

Ball Socket Pipeline Jacket (BSPJ) is a protective system for onshore or offshore pipelines for various industries such as oil and gas, power, fibre optic, etc. The BSPJ were more specifically inspired by the Flexible Threaded Pipe Inserts which was applied for patent in 2014 (Application No: PI2014701177).

The technology came into fruition after requests from clients like PETRONAS regarding high levels of subsea abrasion on their pipelines or cables which would be costly or near-impossible to repair. Most notably the 2014 rupture of the Sabah-Sarawak interstate gas pipeline that caused a temporary shutdown of the multi-billion dollar project owned by PETRONAS [1]. Although the exact root cause was not publicly announced, it was mentioned that the pipelines were laid on the seabed at certain areas.

Currently available in the market for pipeline protection is costly and have high risk e.g. concrete mattress or rock dumping methods. The Ball Socket Pipeline Jacket is designed to have a deployable and swift rehabilitation procedure, affordable and custom-made system. This invention is extremely flexible which could ease installation procedures, and could be exploited to connect pipelines and risers to floaters, manifolds, wellheads, buoys, and platforms, as compared to rigid concrete.

There have been many cases involving the burst of pipelines that result in explosion and fatalities. One of the cases is a gas line explosion in Hinton, Iowa on Wednesday, April 25, 2012, in rural Plymouth County which were a result of an unauthorised excavation job. Two men were injured in the explosion shown in Figure 1.1 below when they hit the 24-inch gas line while digging drainage tile in the farm field. The incident could easily be avoided if the pipelines were to have a protection system such as the Ball Socket Pipeline Jacket that could potentially act as a shield from excavating activities such as this.

FIGURE 1.1: A NATURAL GAS LINE IN A HINTON, IOWA, FIELD THAT EXPLODED WHICH CAUSED TWO MEN TO BE HOSPITALISED [2].

1.2 Problem Statement

There have been a lot of cases of dents and damage caused on flow-lines by third-party activities through accidental or unintentional means which could be easily avoided with having a protection system on the flow-lines itself. The current method is not suitable and must be replaced with something that is much more economical at the same time able to protect from abrasion damage and possible corrosion on the flow-line.

1.3 Objectives

The objectives are as follows:

i. To establish BSPJ as offshore flow-line protection system to shield cables i.e. fibre optic, power, umbilical, flexible and rigid flow-lines, mooring, hoses, and bundled products from abrasion, corrosion, and impact.

ii. To provide a system with custom additional submerged weight that suit the bottom stabilization of offshore flow-lines taking into account that BSPJ could be a sophisticated bending-restrictor system.

1.4 Scope of Study

This will be carried out according to the following focus:

- Through simulating the performance of the BSPJ under critical pressure limit to determine their reliability growth, accelerated life and robust design taking external host pipe damages into consideration e.g. dent depth & percentage, gouges, cracks on the BSPJ. Failure simulation and analysis will be done in ABAQUS software.

- Through scrutinizing a full-scale prototype on environmental and operational conditions i.e. abrasion, erosion, tear, and wrinkles on BSPJ viscoelastic limit.

CHAPTER 2

LITERATURE REVIEW

2.1 Subsea Pipeline Stability

In the background of subsea industry, the integrity of the pipeline is very crucial. Since the 1970, the Pipeline and Hazardous Material Safety and Administration (PHMSA) has been accumulating data on known pipeline failures that occurred within the United States and can be publicly accessed on their website [3]. By using the available information, a study was conducted to statistically correlate the damage sustained by these pipelines and its root cause. It was found that external corrosion is the leading cause for rupture incidents with a corresponding rate of 1.0 x 10-5 per km per year over the period of 2002 to 2013 [4]. Figure 2.1 below shows the rupture rates against the pipe diameter. Evidently, current subsea pipeline requires an additional protection or an alternative piping system altogether.

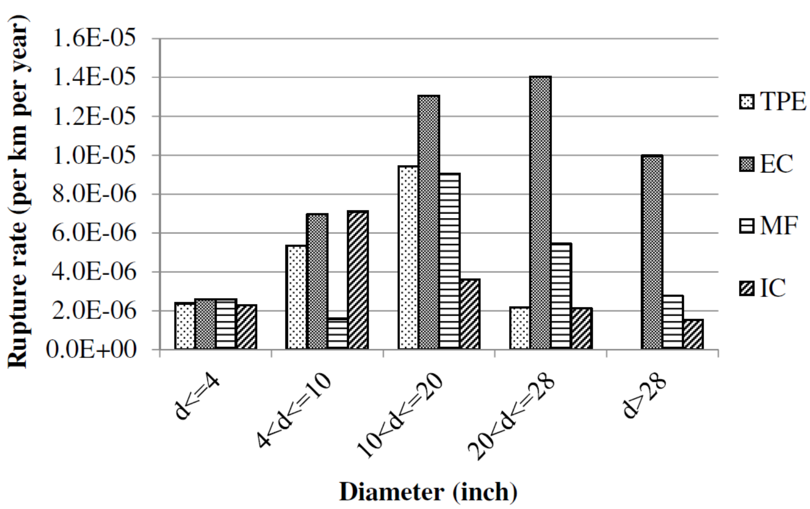


FIGURE 2.1 RUPTURE RATES DUE TO THIRD-PARTY EXCAVATION, EXTERNAL CORROSION, MATERIAL FAILURE, AND INTERNAL CORROSION BY DIAMETER [3, P.36].

2.2 Pipeline Protection Options

TABLE 2.1: SUMMARY OF CABLE PROTECTION OPTION RISK ASSESSMENT [4, P.25]

Option	Deployment Risk	Operational Risk	Navigational Risk	Environmental Impact	Lifetime Cost
Integral Armour	Low	Low	Low	Low	Medium
Concrete Mattresses*	High	High	Medium	Medium	High
Rock Dumping	Medium	Medium	Medium	Medium	High
Anchors or Rock Bolts	High	High	Medium	Medium	Medium
Trenching/Burial	Not Feasible	Not Feasible	Not Feasible	Not Feasible	Not Feasible

Source: Copyright © Nova Innovation 2015 *The same risk assessment applies for grout/rock bags

There are a number of different cable protection solutions that can be considered for subsea cable installation. Based on an assessment on cable protection option, it was found that integral armour has the lowest overall risk. Table 2.1 shows the summary for the risk assessment. Integral armour can be broken down into two categories; Cable Armouring and Outer Jacket.

Cable Armouring involves a sheath of galvanized steel wire, integrated within the cable itself and wrapped around the conducting cores. It offers single, double, triple and variable layer of galvanized armoured cable with double armour being the most preferred because it offers good torque balance, decent safeguard towards abrasion as well as relative ease of termination [5]. While that being the case, it only applies for conducting cables and leaves the cable to be prone for third-party excavation activities.

The second choice for integral protection is by having an outer jacket surrounding the cable. By comparison, outer jacket is the most effective means to protect all cables and pipelines against abrasion due to hydrodynamic loading and impact, both during installation and over the cable lifetime [5]. The Ball Socket Pipeline Jacket (BSPJ) falls into this category and shown in Figure 2.2 as follows.

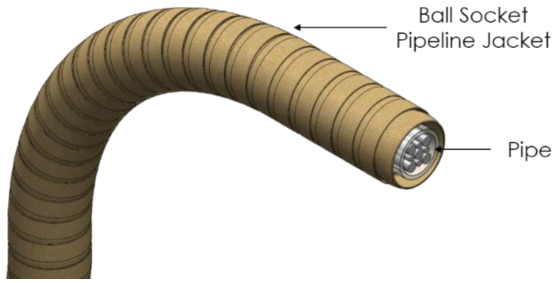


FIGURE 2.2: INITIAL DESIGN OF BALL SOCKET PIPELINE JACKET AS PIPELINE PROTECTION

2.3 Flexible Ball Joint Pipe

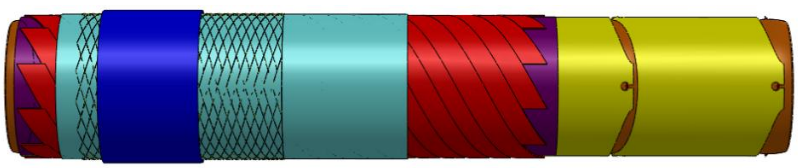


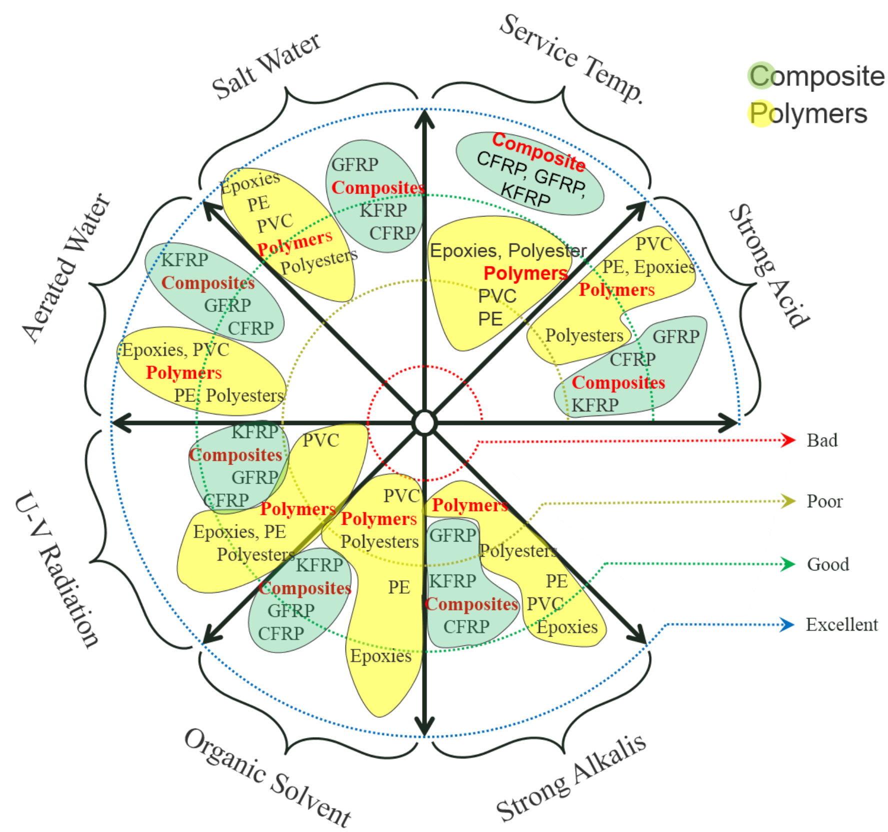
FIGURE 2.3: FLEXIBLE BALL JOINT PIPE

The BSPJ was designed based on the concept of a flexible pipe interconnected using ball joint that possess mechanical resistance to internal and external loads subjected during transportation, deploying, and in operation. Apart from that, it must be resistant towards physical, biological and chemical nature related to the quality of the conveyed water and to the soil. Furthermore, the ease and safety of installation as well as comprehensive optimal cost, considering not only the materials and installation but also maintenance and duration of use.

In order to prevent the disassembling of the pipe coupling, the ball joints will be provided with four pins on its outer surface, while the pipe elements will be provided with a stop hole pressing against the pins. The pipe segments are assumed to be covered by elastic filler filled in valley gaps on an outer peripheral side to provide a continuous barrier layer against permeation of conveyed fluid. One or more helical wounding tape stacks applied to the internal liner for absorbing axial and bending loads as seen in Figure 2.3. A structural composite element e.g. Fibre reinforcing polymer. Currently, the pipe would be a male mould for filament winding process and such paradigm produce pipes of highest mechanical performance, since the quantity of reinforcement that can be incorporated in the matrix is higher [6].

2.4 Material Selection

The Ball Socket Pipeline Jacket must be made out of composite material that have high resistance towards seven common environments. Figure 2.4 shows what type of composite and polymers that are bad, poor, good, and excellent resistors towards the types of environments stated.



Courtesy of Dr. Dher Mohammed Badri Albarody. © Petroliam Nasional Berhad (PETRONAS) 2014

FIGURE 2.4: COMPARATIVE RANKING OF THE RESISTANCE OF MATERIALS TO ATTACK BY SEVEN COMMON ENVIRONMENTS

The proposed composite material composition by using glass fibre reinforced polymer (GFRP) are shown in Figure 2.5 to make the prototype for testing.

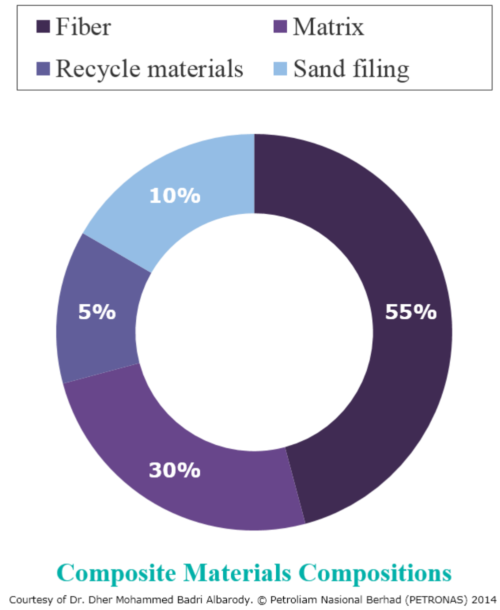


FIGURE 2.5: COMPOSITE MATERIALS COMPOSITION

Recyclable materials such as coco peat can be used which acts as a filler to enhance the bonds of the glass fibre used in the epoxy or resin [7] as it is cheap and abundantly available in Malaysia.

2.5 Benchmark on Current Technologies

There are many available products that are ready to be used by key players in the industry such as PETRONAS with each having their own pros and cons. This sub-chapter lists down four major products that acts as protection system on cable and flow-lines.

2.5.1 Subsea Umbilical Riser Flowline Solutions by BARDOT Group

One of the main competitors in Malaysia in the pipeline protection system is from Bardot Group with their concept of having low capital expenditure (CAPEX) and operational expenditure (OPEX) which they call it the LowPex® philosophy [8].

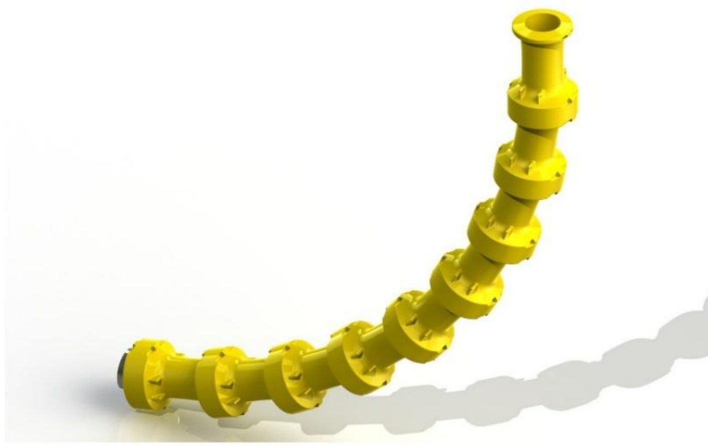


FIGURE 2.6: BEND RESTRICTOR BY BARDOT GROUP [9]

The Bend Restrictors which is part of their Subsea Umbilical Riser Flowline Solutions (SURF), are made of Polyurethane (PU) material and have been tested and dedicated for extreme subsea loading applications that allows significant weight in water and air reductions. Installation of the Bend Restrictors uses an interlocking system which is made of half shells bolted together with high grade stainless steel fasteners [9].

This product uses the concept of providing protection of over-bending once it reached the minimum bending radius similar to the Ball Socket Pipeline Jacket. Apart from that, since the Bend Restrictors by BARDOT Group is made from Polyurethane, it could not handle with high temperature and only adds an internal thermal protection shield in the case of high operation temperature which could increase in capital cost.

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2.5.2 VerteBrace® Bend Limitors and ProShell HD® by BMP Proteus

Another competitor of BSPJ is the products made by BMP Proteus which focuses on the manufacture of advanced polyurethane equipment that includes bend restrictors and ballast protection systems.

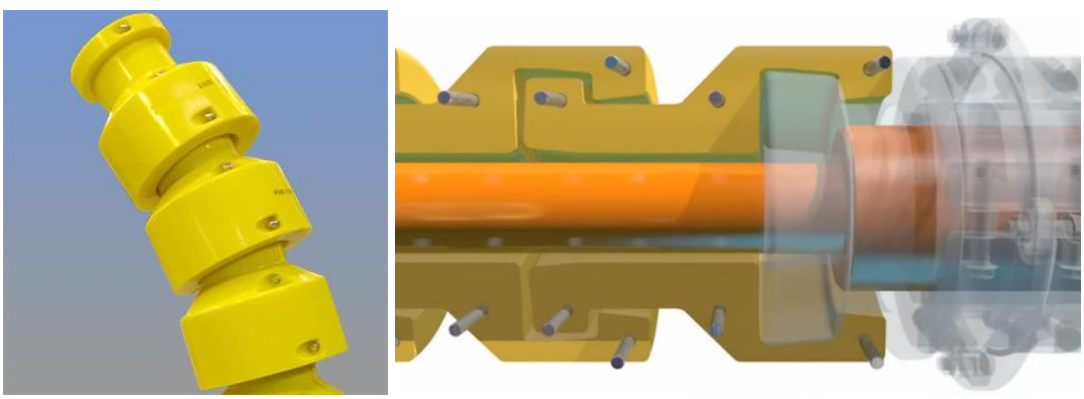

FIGURE 2.7: VERTEBRACE® BEND LIMITORS [10]

BMP's VerteBrace® Bend Restrictor System uses a two-part modular design which are connected via screws and could incorporate seamlessly into other BMP's subsea protection products such as ProShell HD® [11].

FIGURE 2.8: BALLAST PROTECTION THAT USES METAL KITES AND STRIPS [12]

This company also makes ballast protection system called ProShell HD® (High Density) that contains heavy filler materials and place lead inserts which would increase density and overall weight resulting an improved on-bottom stability [13].

Similar to BARDOT Group, BMP uses Polyurethane as the main material for their products. Even with the modular design by BMP, the parts will still need the use of screws and metal strips to be attached together which is not the case for Ball Socket Pipeline Jacket that incorporates the design of ball and socket joints. This would eliminate the need of any external pins or other metal that could cause corrosion in subsea condition.

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2.5.3 Umbilical Protection by BRI Offshore

An almost similar to the product by BMP Proteus is the umbilical protection system made by BRI Offshore that uses the vertebrae bend restrictor (VBR). The bend restrictor comprises of individual element that interlocks within another like vertebrae and connected together with corrosion resistant fasteners [14].

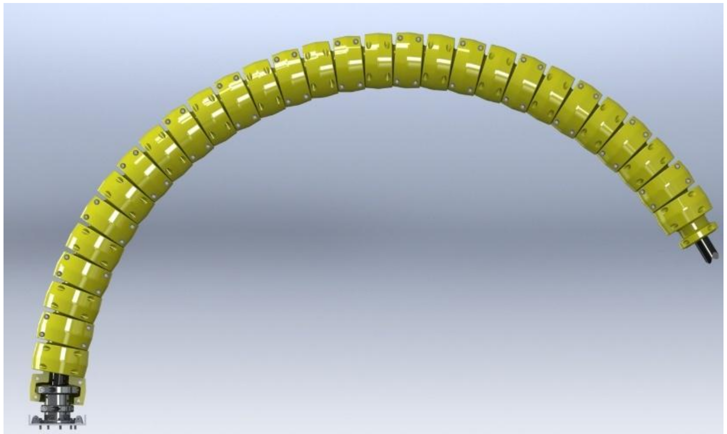

FIGURE 2.9: UMBILICAL PROTECTION USING VERTEBRAE BEND RESTRICTOR [14]

Problem occurs when the polyurethane material is too soft to handle the loading of the pipes and damage due to excavation activities as well as anchoring or other mechanical impacts on the system which could lead to the pipes being exposed either way. Other than that, the fasteners are a limiting factor as well and could increase the chances of failure for the parts. Therefore, BSPJ avoids using polymers by replacing the material fully with a composite that is stronger than concrete and has the capabilities of getting the impact without the need of using a fastener thus reducing the odds of failure.

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2.5.4 Uraduct® by Trelleborg Offshore

The Uraduct® is a protection system built for any area where abrasion is treated as a problem and stabilisation is difficult to achieve. It is said to have custom made system while being easy to handle and transport. The product has different variants and each meets their own purpose i.e. Buoyant Uraduct® which has custom buoyancy and minimizes drag; Ballast Uraduct® have different weights and sizes according to the customer's requirement; Uraduct® + has simple installation process which is considered to be the ultimate protection solution by the company [15].

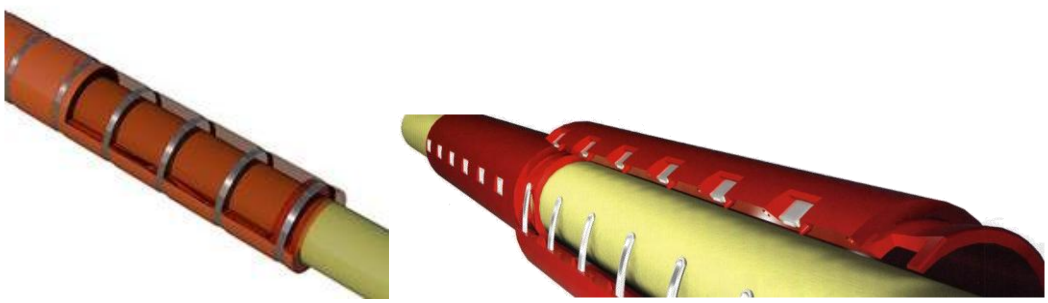

FIGURE 2.10: THE BALLAST URADUCT® (LEFT) AND URADUCT® + (RIGHT) THAT USES METAL STRIPS [15]

The BSPJ takes advantage by having made using composite unlike the Uraduct® protection system which uses plastic thus may be exerted to a higher impact force. Other than that, the BSPJ avoids using any possible corrosion-prone metal strips as fasteners owing to the locking mechanism of the ball and socket joints design.

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2.6 Analysis Approach for On-Bottom Stability

The Finite Element Analysis (FEA) will be conducted using ABAQUS to simulate critical conditions being exerted on the BSPJ and their effects on the material used. Since BSPJ will mostly be used in pipelines with overcomplicated domains like highly nonlinear phenomena i.e. eddies in the ocean and interaction with the seabed [16], it is imperative to produce near-accurate assessments with numerous force-resultant models in the stability analysis of long on-bottom pipelines [17].

2.6.1 Design Principles and Methods

Based on an absolute Lateral stabilities criteria the environmental conditions, such as waves, currents, water depth and seabed roughness, are major factors that used in shaping the hydrodynamic loads on the non-metallic pipe (NMP). Although, in practice the NMP may experience considerable movement or embedment during resting on the seabed, we will present an approach to account for these effects transiently using absolute Lateral stabilities at each second of exposure to hydrodynamic forces as shown in Figure 2.11.

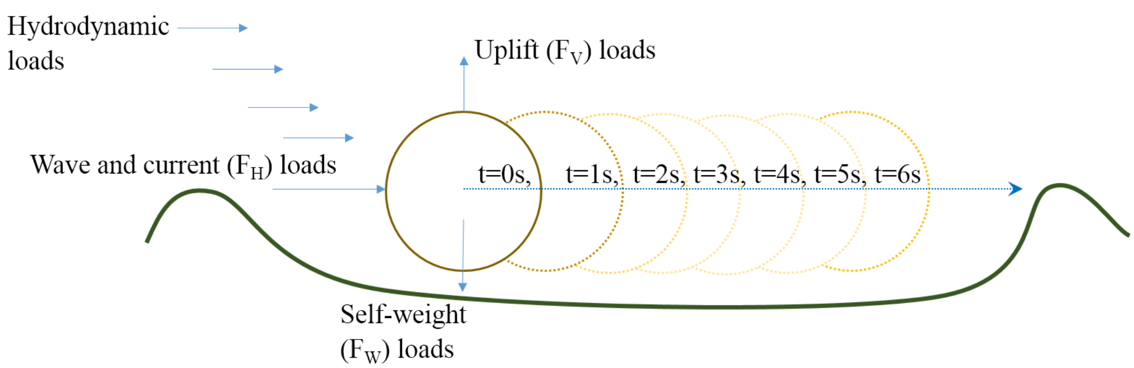

FIGURE 2.11 TRANSIENT ABSOLUTE STABILITIES CRITERIA.

Wave and current are assumed to cause horizontal (F_H) and vertical uplift (F_V) loads on the pipeline. The hydrodynamic loads acting on the NMP are usually calculated for pipe invert touching the seabed. However, the OBS design principles and methods explained in Figure 2.12.

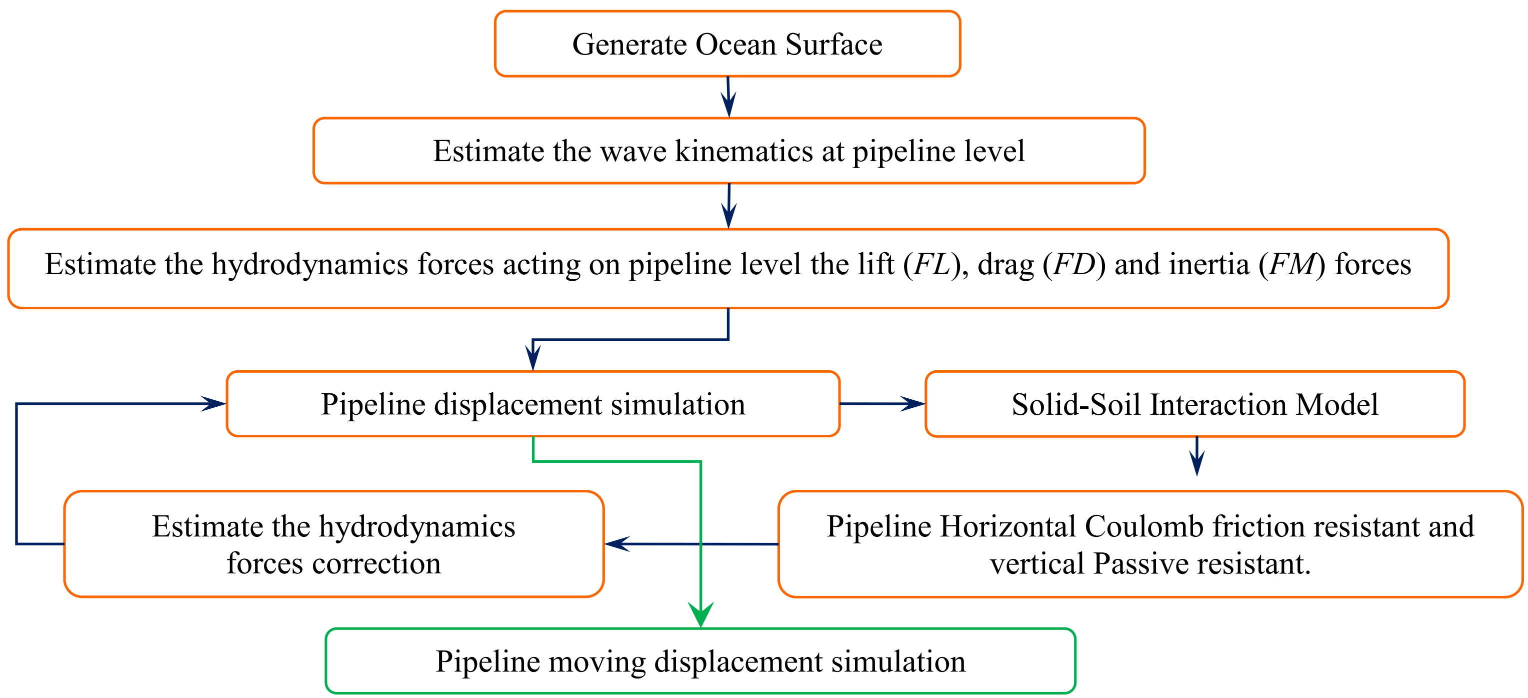

FIGURE 2.12: ON-BOTTOM DESIGN PRINCIPLES

2.6.2 Hydrodynamic Load Modelling

Figure 2.13 below shows fundamental steps to evaluate flow induced vibration near NMP pipeline. Whereas, three dimensional wave spectrum with spreading function and linear wave theory are used to generate the ocean surface. Then linear wave theory is used to transfer the wave kinematics to the NMP pipeline level.

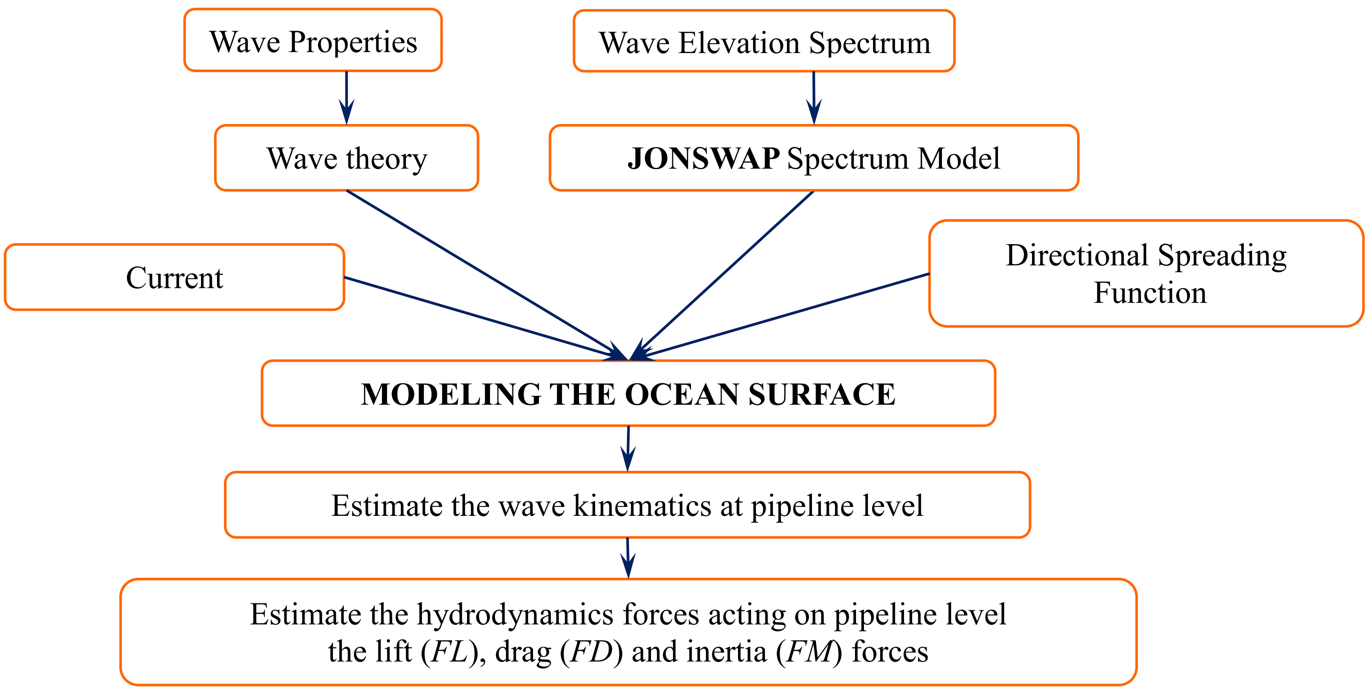

FIGURE 2.13: HYDRODYNAMIC MODELLING SEQUENCES USED IN ABAQUS SUB-ROUTINE

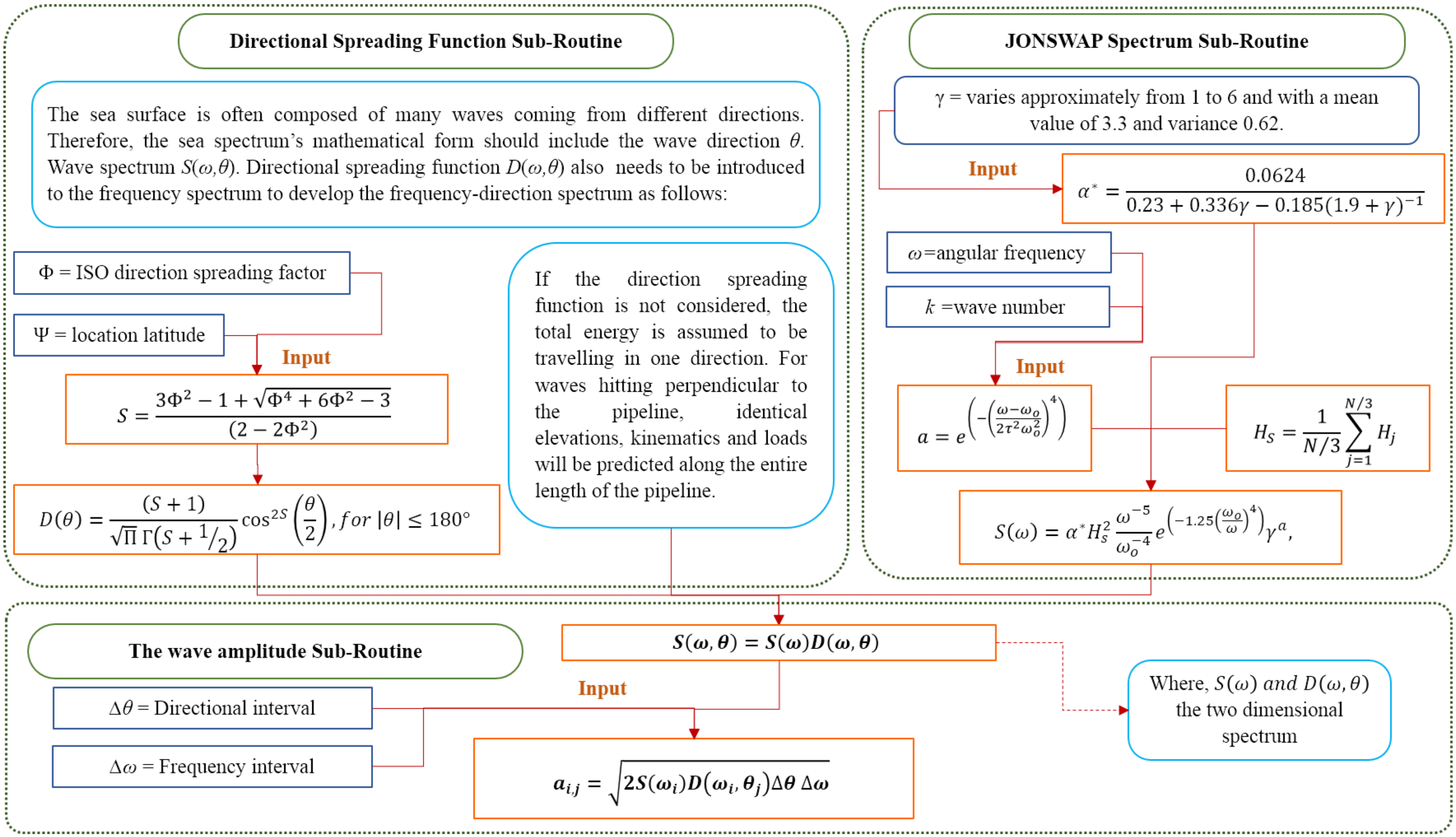

FIGURE 2.14: OCEAN SURFACE SUBROUTINES USED IN ABAQUS

2.6.3 Wave Properties

Ocean waves can be described as a series of individual waves of different heights, periods and limited crest lengths. Equation 2.1 shows a zero-down crossing analysis to measure significant wave period [18], [19].

$$T_s = \frac{1}{N/3} \sum_{i=1}^{\frac{N}{3}} T_i \qquad (2.1)$$

$$T_s \approx 0.95 T_p \quad \text{(for wind sea)} \qquad (2.2)$$

$$T_s \approx T_p \quad \text{(for swell)} \qquad (2.3)$$

Where,

T_s = Significant wave period

T_p = Peak wave period

N = Number of waves

i is the rank number of the wave, based on wave height, i.e. *i* = 1 is the highest wave, *i* = 2 is the second highest wave, etc.

2.6.4 Current

For the on-bottom pipeline stability design, the steady average current over the pipe diameter should be used [20]. A more accurate simulation of the wave kinematics, the directional spreading function should be applied on simulating the ocean surface.

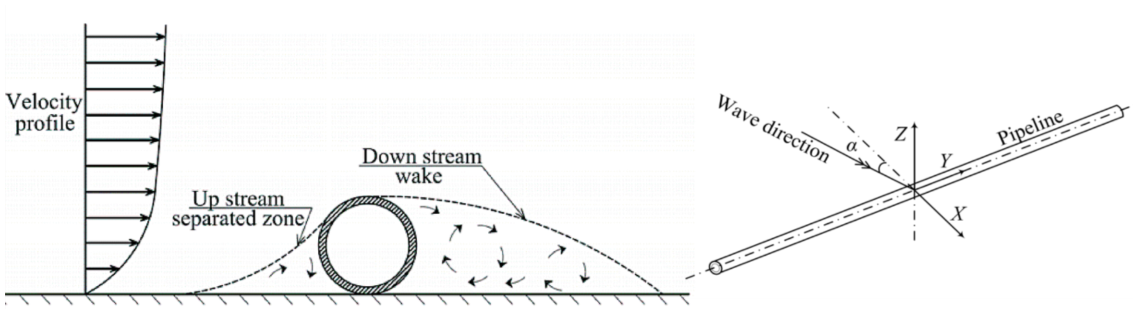

FIGURE 2.15: DIAGRAM OF STEADY CURRENT OVER PIPELINE

2.6.5 Hydrodynamic Forces Modelling

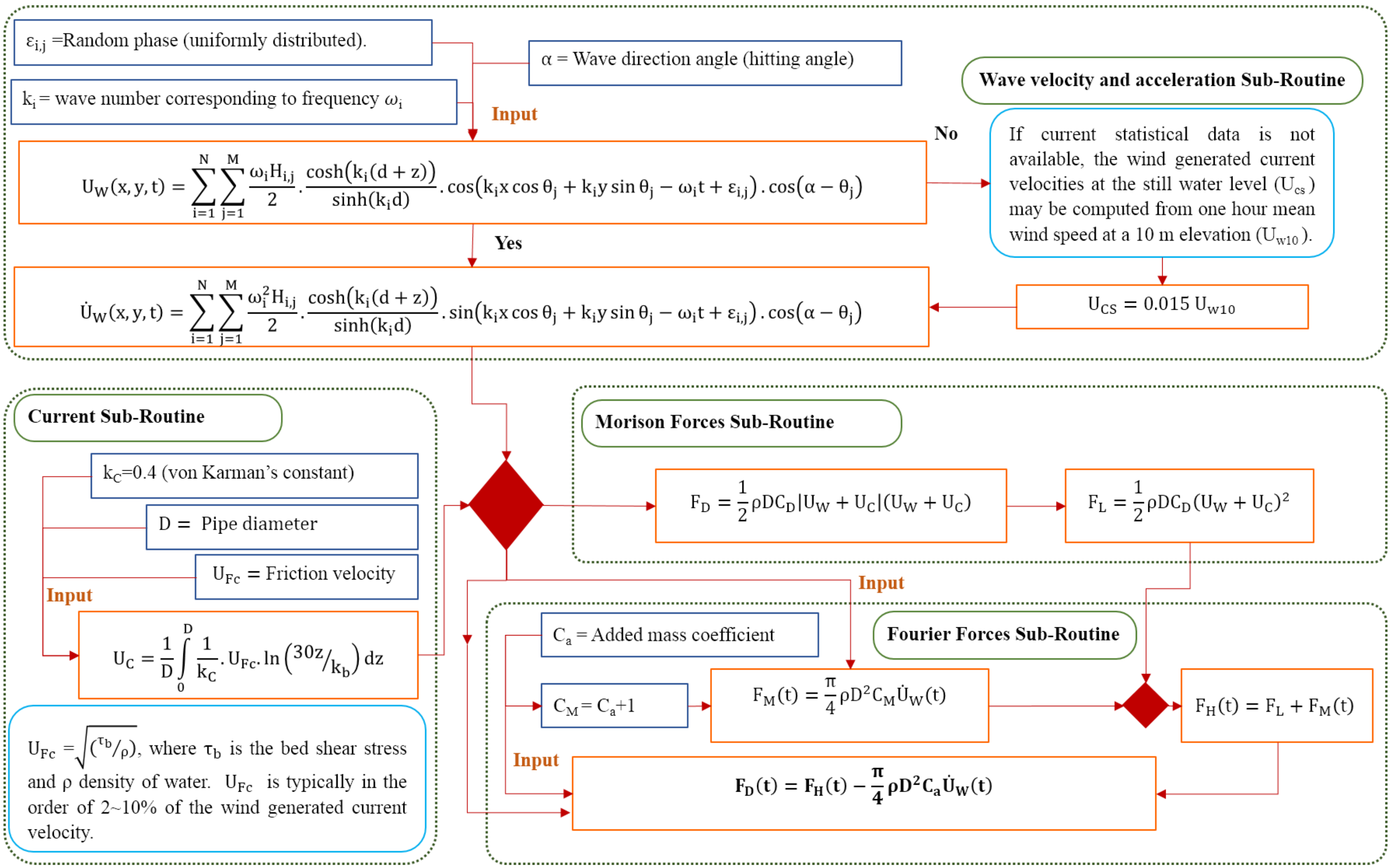

FIGURE 2.16: HYDRODYNAMIC FORCES SUBROUTINES USED IN ABAQUS

2.6.6 Adaptation of Irregular Waves

Fourier coefficient for each half cycle were adapted from the regular wave force coefficients according to the half cycles values for KC_i and M_i , where K_i has the form $KC=U_{Wi}T_i / D$ and M_i is defined as $M_i=U_C /U_{Wi}$, while i is the half cycle number as shown in Figure 2.17 below.

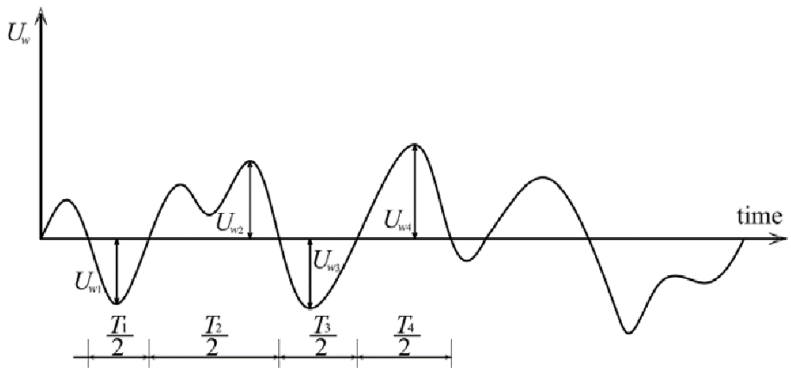

FIGURE 2.17: DECOMPOSITION OF IRREGULAR WAVE INTO REGULAR WAVES

2.6.7 Pipeline Penetration

Pipeline-Penetration correlation of reduction factors shown in Figure 2.18 will be used to update the subroutine to modify the NMP pipeline position in ABAQUS during simulation allowing NMP to further penetrate due to dynamic cyclic movements [21].

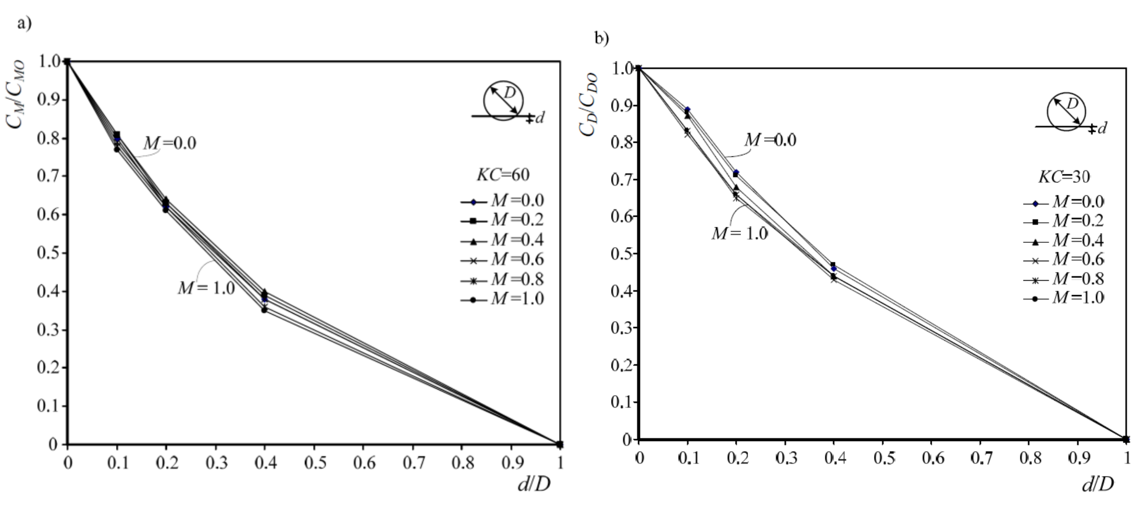

FIGURE 2.18: REDUCTION FACTORS FOR (A) INERTIA AND (B) DRAG FORCE

2.6.8 Pipeline Uplift Off the Seabed

For the case of NMP uplifting with a gap to the seabed, the following correlation to determine the drag, inertia, and lift coefficients used to update the current subroutine modifying NMP pipeline position in ABAQUS during simulation [22], [23].

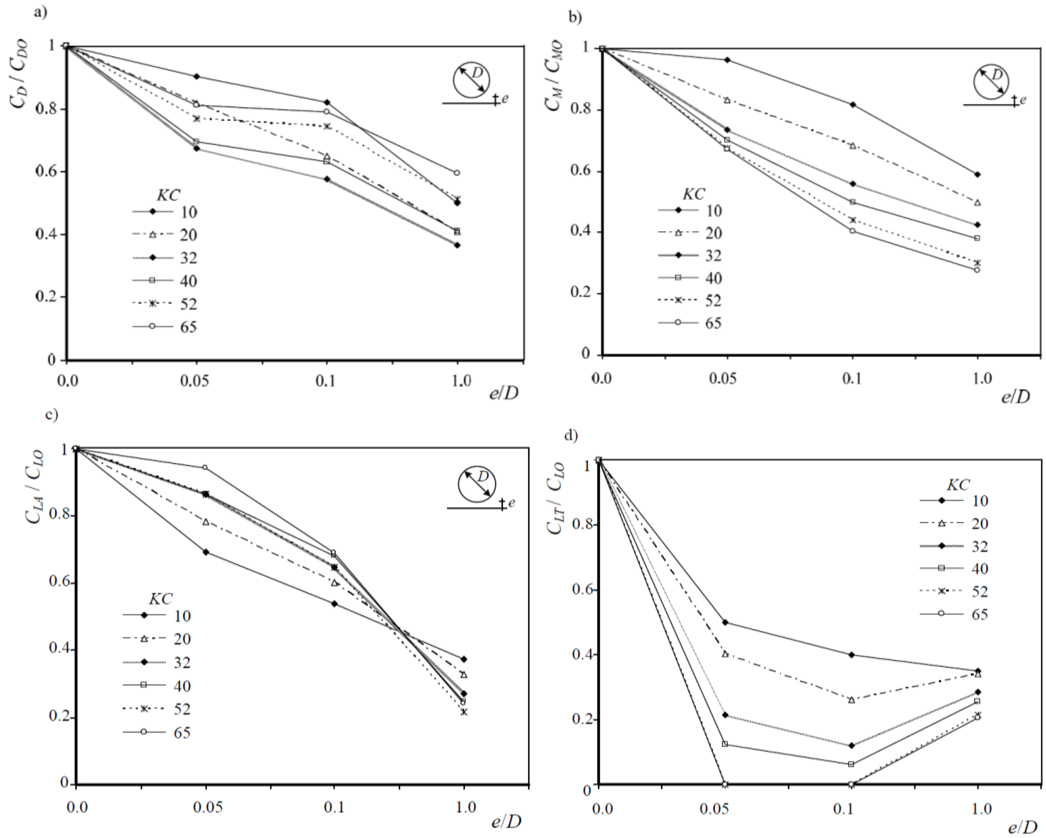

FIGURE 2.19: REDUCTION FACTORS FOR (A) DRAG, (B) INERTIA, AND (C,D) LIFT FORCES

2.6.9 Pipeline Horizontal Movement and Hydrodynamic Load Correction

Lift, Drag, and Inertia Loads calculated by Hydrodynamic Loading subroutine will be corrected and to update the pipe movement, the following correlations will be used [24]. Correction would be based on relative pipe-flow velocity ($U_e – U_p$) where U_e is near pipe (eff) velocity & Up is actual pipe velocity.

TABLE 2.2: EQUATION OF CORRECTION FACTORS FOR LIFT, DRAG, AND INERTIA LOADS

Expression for Near Pipe Velocity	Expression for Drag & Lift Force	Equation for Lift & Drag
$U_{NP} = \sqrt{\left(\frac{F_D{}^t}{1/2\,\rho D C_D}\right)\left(\frac{F_D{}^t}{\lvert F_D{}^t \rvert}\right)}$	$F_D{}^t = \frac{1}{2}\rho C_D D \lvert U_{NP} - U_P \rvert (U_{NP} - U_P)$ $F_L{}^t = \frac{1}{2}\rho C_L D (U_{NP} - U_P)^2$	$F_I{}^t = \frac{\pi D^2}{4}\rho C_M \dot{U}_t + C_a \frac{\pi D^2}{4}\rho \dot{U}_P$

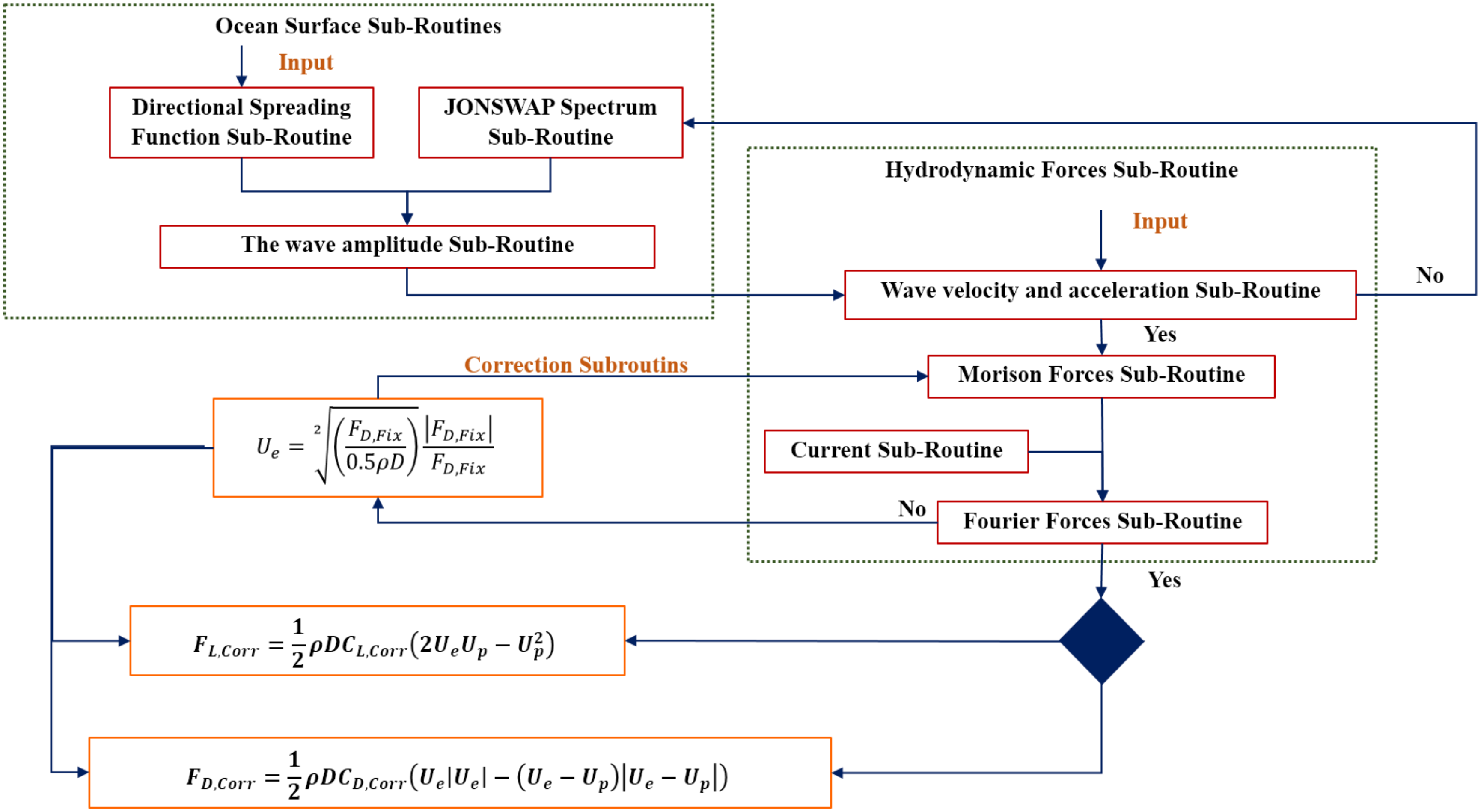

FIGURE 2.20: DRAG AND LIFT FORCE CORRECTION SUBROUTINES USED IN ABAQUS

2.6.10 Pipe-Soil Interaction Subroutines

In NMP simulation we have used the Pipe-Soil Interaction model based on centrifuge experiments on kaolin clay [25], [26]. Pipe-Soil Interaction subroutines are developed to work with ABAQUS updating the hydrodynamic forces subroutine providing vertical/normal pipe support equilibrium and lateral/tangential pipe resistance. However, the passive resistance is modeled as part of subroutine.

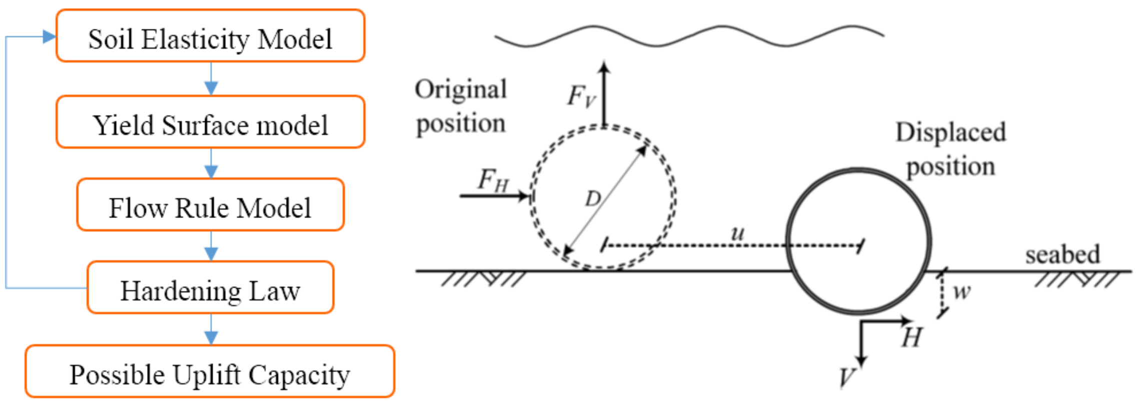

FIGURE 2.21: PIPE-SOIL INTERACTION SUBROUTINES USED IN ABAQUS

- Embedment based on principles by Verley RLP & Sotberg T (1992) [Sand] and Verley RLP & Lund KM (1995) [Clay]. Whereas calculated embedment used to determine passive resistance-force displacement curve.

2.6.11 Pipe-Soil Interaction Subroutine Facilities

i. Deformable soil.

ii. Both Flat and Irregular seabed.

iii. Interaction between Seabed/Pipe defined by “soften contact with linear contact pressure and over closure relationship”.

iv. Tri-Linear Coulomb Friction model for Pipe Axial & Lateral Direction

v. Predicts pipe embedment and associated increase in soil resistance.

vi. Both Sandy and Clay Soil

vii. Development of embedment calculated based on work done on seabed by pipe displacement [27], [28].

viii. Calculated embedment used to determine passive resistance-force displacement curve.

$$\frac{z_2 - z_1}{D} = 0.23\left[\frac{E}{\gamma_s D^3}\left(\frac{\gamma_s D^2}{F_{Ci}}\right)^{-1}\left(\frac{y}{D}\right)^{-\frac{1}{2}}\right]^{0.31} \tag{2.4}$$

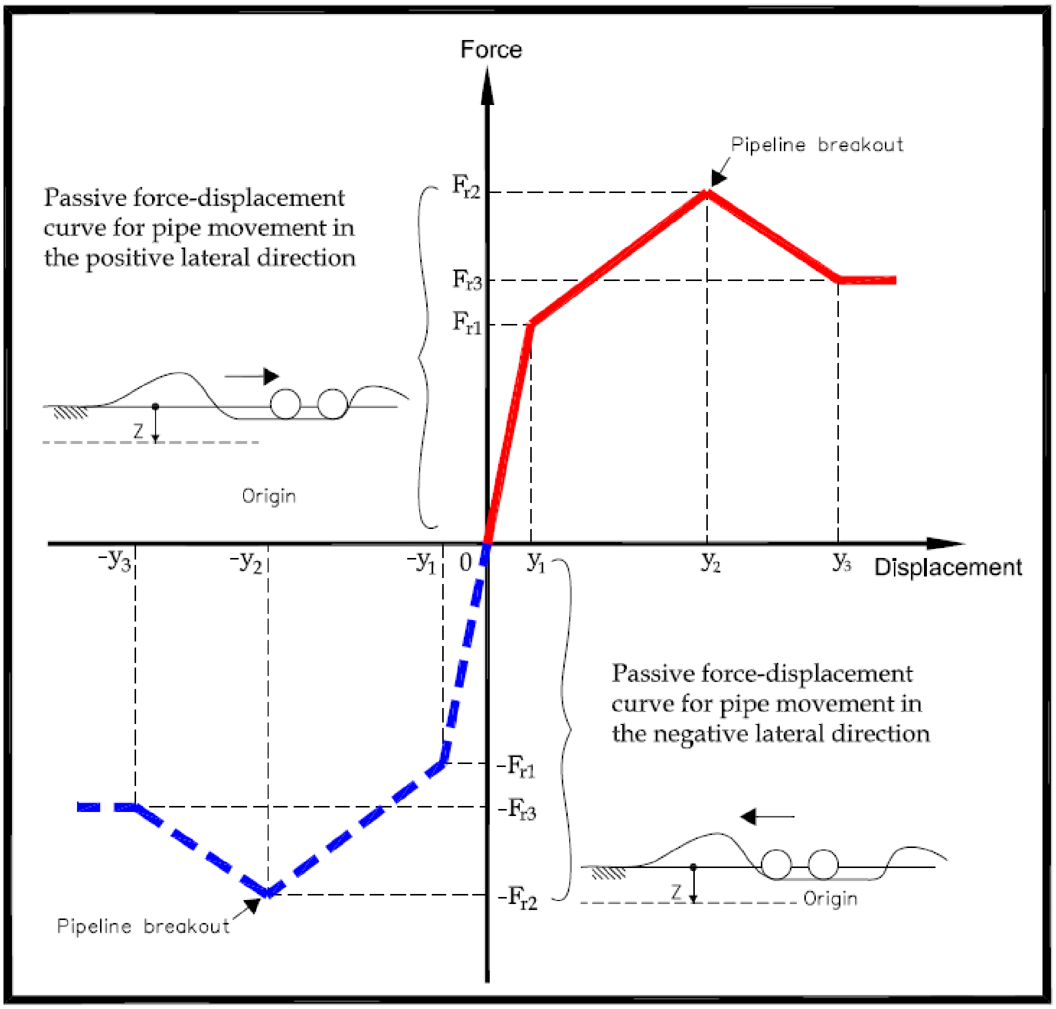

FIGURE 2.22: GRAPH OF PASSIVE RESISTANCE AGAINST FORCE DISPLACEMENT

CHAPTER 3

METHODOLOGY

3.1 Introduction

This project uses the following process in Figure 3.1 throughout the project to ensure a smooth flow.

FIGURE 3.1: PROJECT FLOWCHART

This approach studies the contrasts and similarities using comparative benchmarking of other available products with the BSPJ through continuous identifying, understanding, and adapting outstanding practices [29]. The study sought to evaluate how other products operate as an off-shore protection system.

The fabrication of the BSPJ prototype will be based on an optimised design that could reduce the installation time. Parts will be made of non-metal material which has resistance towards seven common environments which will be elaborated further in Literature Review under Chapter 2.4 Material Selection.

Simulation of the BSPJ is analysed under environmental and operational conditions on BSPJ viscoelastic limit in accordance with DNV-RP-F109 using multiple principles working together to imitate the real-world subsea conditions. This numerical analysis is based on the design method using static and dynamic absolute lateral stability using the recommended practice under DNV-RP-F109 [30].

Since the technology of Ball and Socket pipes have been spearheaded by Dr. Dher Mohammed Badri Albarody [6], the project will proceed according to Table 3.1 as shown below.

TABLE 3.1: TECHNOLOGY READINESS LEVEL (TRL)

TRL Level	Work Scope
0	Research begins at TRL 3 since BSPJ concept has already been validated and proofed using physical model tests. The BSPJ design has been verified its functionality has been scrutinized in the laboratory.
1	
2	
3	Prototyping according to performance, reliability growth, accelerated life and robust design tests accounting influences of external host pipe damages: dent depth & percentage, gouges, cracks on BSPJ critical pressure limit.
4	Full scale prototyping and applying qualification program scrutinize environmental and operational conditions: abrasion, erosion, tears, and wrinkles on BSPJ Viscoelastic limit.
5	Construct production BSPJ unit and applying operational interface and functional test.
6	BSPJ demonstration by applying full operational interface and function test program
7	BSPJ field proven scrutinizing acceptable reliability and risks of early life failure in the field.

3.2 Detailed Project Flowchart

Figure 3.2 below shows a flowchart of the prototype development strategy that will be conducted to achieve completion of the project. The steps shown are based on the optimization phase accomplished using internal funding grant prior to the qualification documentation and assessments.

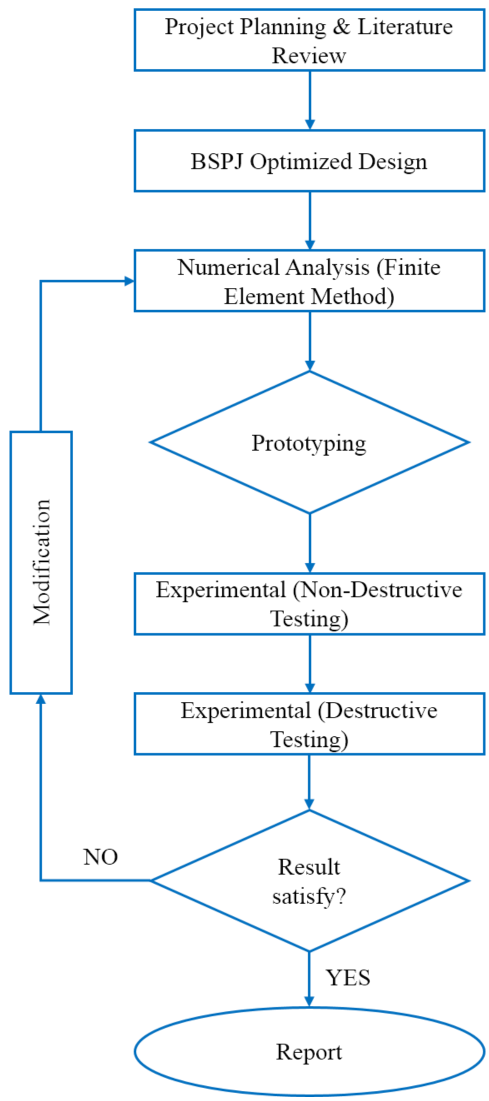

FIGURE 3.2: FLOWCHART OF BSPJ OPTIMIZATION PHASE

The fabrication in this project is divided into two phases; Optimization Phase; Evaluation & Pre-Customization Phase as shown in Figure 3.3.

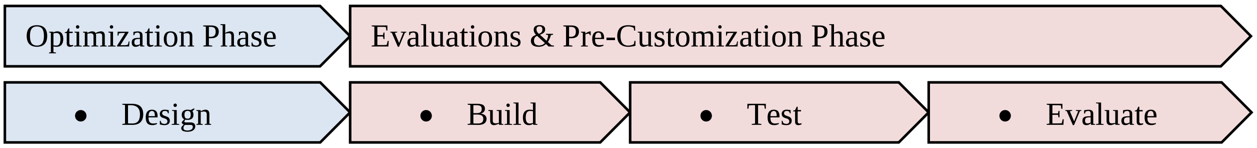

FIGURE 3.3: GENERAL FABRICATION PROCESS

3.3 Optimised Design

In order to reduce installation time with the ease of fabricating, a new optimised design have been created. Figure 3.4 shows the difference of design in the BSPJ part most significantly is the slotted section. With the changes made, it would be much easier to fabricate by way of avoiding complex machining.

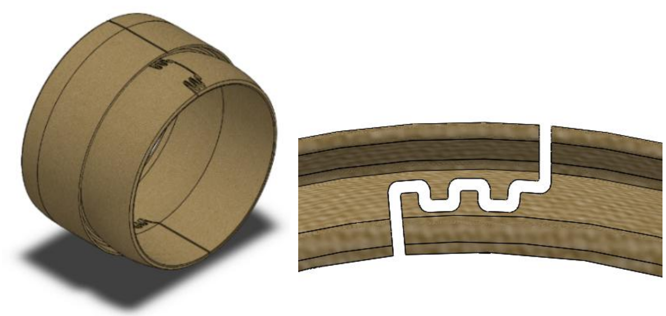

FIGURE 3.4: OLD BSPJ DESIGN WITH ASSEMBLY SLIT

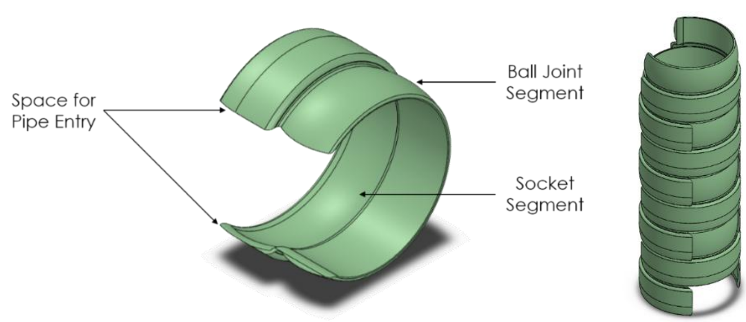

FIGURE 3.5: NEWLY IMPROVED BSPJ DESIGN

3.4 Design of BSPJ Die

In order to produce the Ball Socket Pipeline Jacket (BSPJ) with a composite material, a suitable method is through liquid composite moulding [31]. The die will be designed to ease mass production that permits the use of glass composite as raw material. With the optimised design of BSPJ, we can design a mould using exterior and interior dies. The mould also features four holes to insert M12x1.50x70mm screws to provide tight fastening when mixing the composite materials. Figure 3.6 shows the exploded view of the proposed mould that will be used for fabrication.

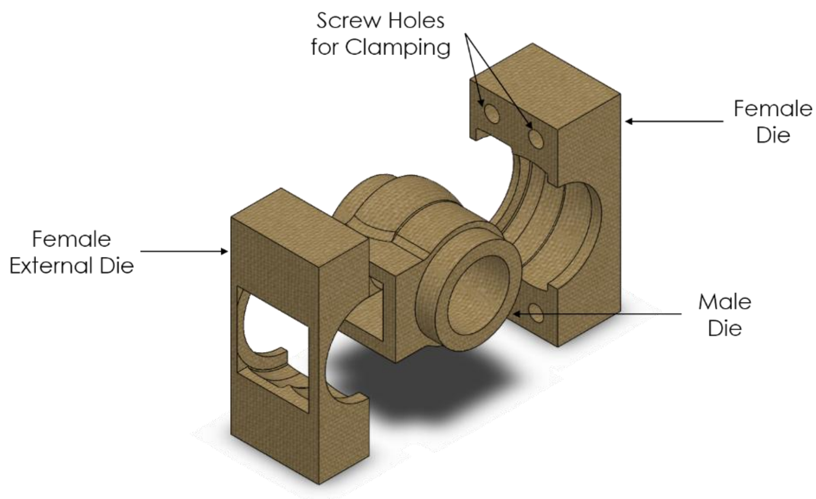

FIGURE 3.6: EXPLODED VIEW OF MOULD

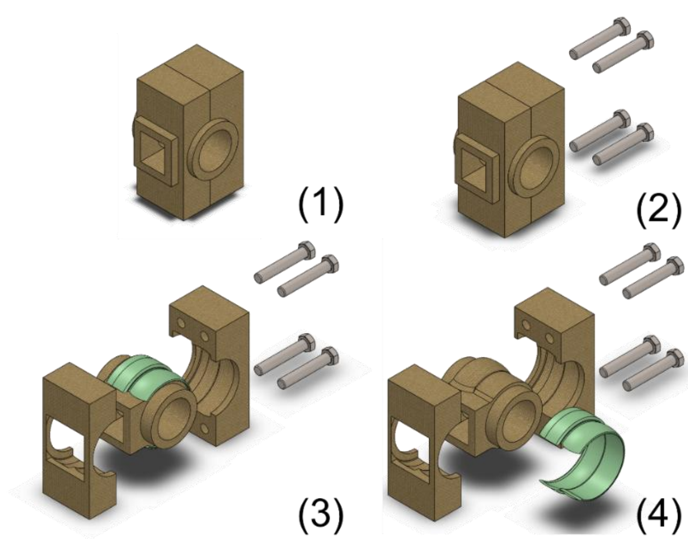

FIGURE 3.7: DISASSEMBLY OF MOULD AND PART

3.5 Previous Versions of the BSPJ Die

The improvisation of the prototype was made gradually by changing the design with the purpose of easing the installation and reducing the total volume thus making the part to be cost effective using less materials. Design C has been chosen for manufacturing and prototyping purposes. Figure 3.8 shows the previous designs that was improvised over.

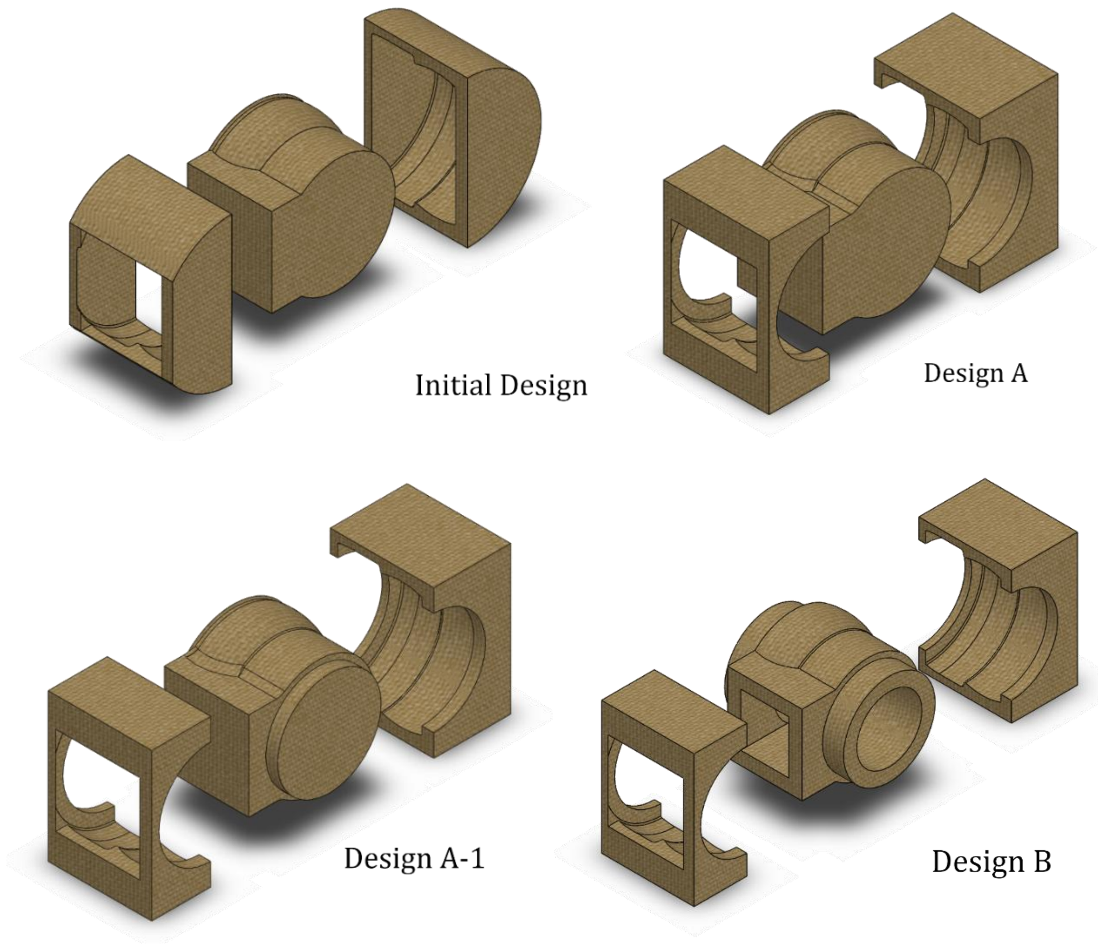

FIGURE 3.8: PREVIOUS DESIGNS OF DIE ASSEMBLY

3.6 Die Fabrication

The die will be made of cheap material like Aluminium that is strong enough to sustain the composite mixture of the BSPJ parts. Fabrication is done at the Design & Prototyping Center (DPC), Universiti Teknologi PETRONAS (UTP), Seri Iskandar, Perak, Malaysia using the Mazak 6-Axis CNC machine. Please refer Appendices for the drawings submitted.

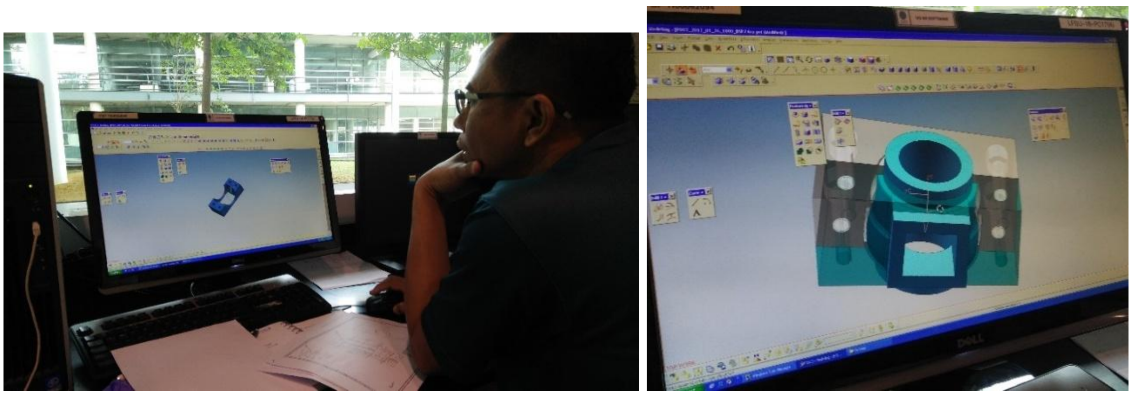

FIGURE 3.9: DPC MACHINIST WITH CNC SOFTWARE

FIGURE 3.10: MAZAK VARIAXIS 630-5X CNC MACHINE

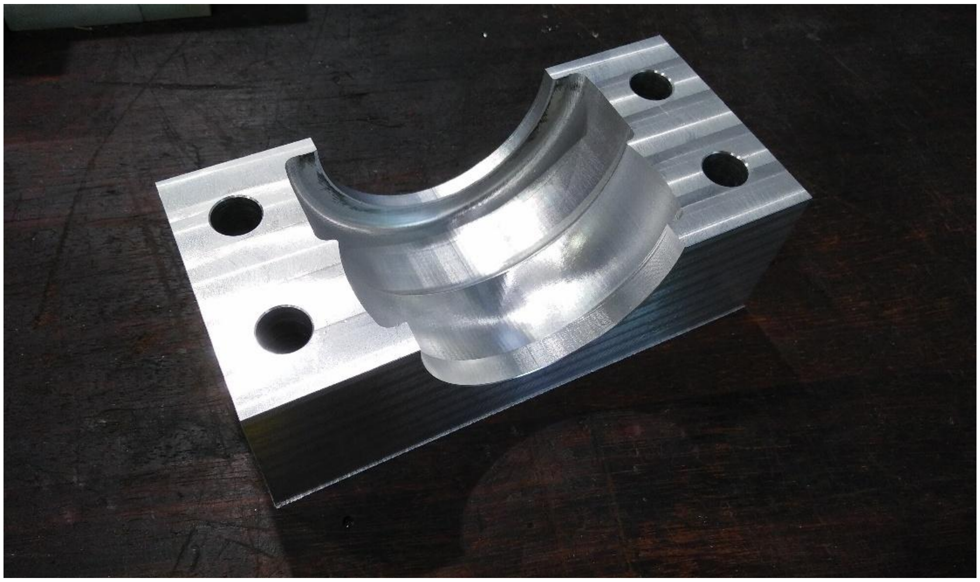

FIGURE 3.11: FEMALE DIE FABRICATED BY DESIGN & PROTOTYPING CENTRE (DPC)

Machining of the die must be done with high precision to avoid any linings or cracks when mixing the composite later on. Pitting is recommended to ensure smooth surface which ultimately would produce a fine BSPJ part. The male die will be placed in between and is aligned using the semi-circular edge on each of the female die. The external female die is threaded with M12x1.5x70mm to provide alignment and tightening of the two female dice.

3.7 Assembly of Parts

With the use of a hydraulic presser from a car workshop, two ball socket parts are stacked on top one another and pressed perpendicularly.

FIGURE 3.12: BALL SOCKET JOINTS BEING PRESSED

3.8 Simulation and Testing

To ensure the on-bottom stability of the pipeline using standard practice as outlined by DNV-RPF109. The geometry of the BSPJ must be analysed at difficult position of the pipe which may be a focal point of stress. The maximum limit before failure must be determined to introduce a safety factor consequently optimizing the model even further.

Integrated hydrodynamic pipe-soil modelling and added weight model:

i. NMP pipeline will be modelled as 400m in length and fixed from both side

ii. NMP modelled in touch with seabed

iii. Pipeline will be modelled as 400m Shell Elements

iv. Added Weight (i.e., the Chain) will be modelled as Bundle Rod has fixed cross-section so that the weights manipulated throughout the density of rod. This method takes into account the added weight and drag areas

v. Composite Stiffness used, no independent layer stiffness will be modelled

vi. Non-Linear geometry and stress stiffening effects accounted for by updating stiffness matrix in time domain

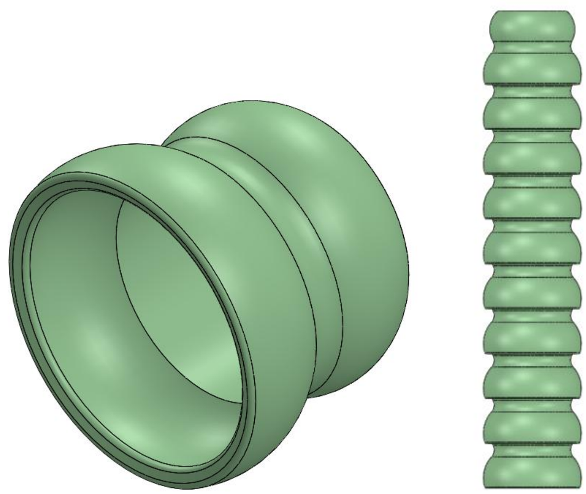

FIGURE 3.13: NEW DESIGN FOR ABAQUS SIMULATION

Once the fabrication of the part is done, physical testing can be executed through various non-destructive testing and followed by destructive testing to completely assess the BSPJ under scrutinizing conditions conducted in the laboratory.

CHAPTER 4
RESULT AND DISCUSSION

With the newly revised design of the Ball Socket Pipeline Jacket, it relates to one or more embodiments of and methods to make flow-lines heavy-laden enough to fit subsea stability requirements. The rigid massive jacket comprises of a series of interconnected ball-and-socket sections forming jacket that could be positioned and bendable which could absorb tension loads, as well as bending loads. Jacket segments are design to be snappingly engageable and maintain the pipeline flexibility as the pipeline weight wall and thickness increases. The ball and socket segments are assumed manufactured from a thermosetting material composited filled and laden with heavy sand and reinforced by short discontinues glass fibres i.e. Glass Fibre Reinforced Polymer (GFRP).

The following tables shows the observation on Non-Metallic Pipe (NMP) after simulation.

TABLE 4.1: CHARACTERISTICS OF THE NMP

Characteristics		**NMP Pipeline Specialist Group**		**Airborne**
Pipe diameter; ID: 152 mm, and OD: 205 mm		**Single layer**	**Total**	
NMP volume	Liner: Polyamide (PE)	5.6329e-003 m^3/m	1.48e-002 m^3/m	N/A
	Structural Layer: Glass Fibre/Polyethylene	3.6312e-003 m^3/m		
	Jacket: Polyamide (PE)	5.5359e-003 m^3/m		
Internal volume		1.815 e-002 m^3/m		N/A
External volume		3.301e-002 m^3/m		N/A
Empty weight in air	Liner: Polyamide (PE)	5.3512 kg/m	16.758 kg	16.9 kg/m
	Structural Layer: Glass Fibre /Polyethylene	6.1476 kg/m		
	Jacket: Polyamide (PE)	5.2591 kg/m		

TABLE 4.2: NMP WHEN FULL OF SEAWATER

Weight full of sea water in air			35.357 kg/m	N/A
Empty weight in sea water	Pipe completely floating		-17.0773 kg/m	N/A
Weight full of sea water in sea water			1.588 kg/m	1.5 kg/m
Floatability factor empty in sea water	Floatability factor = Empty weight in air / (External volume × 1.02 × Density of sea water).		0.4855708	N/A

TABLE 4.3: NMP OPERATIONAL LIMITS

Bursting pressure	Estimated by FE software considering NMP at external hydrostatic pressure = 10 MPa or under 100m seawater depth	≈ 13±2 MPa	N/A
Collapse pressure	Estimated by FE software considering NMP at minimum internal operating pressure 3.1 MPa	≈ 6±2 MPa	N/A
Max allowable strain	We have assume fiber orientation ≅55°	0.9%	3.3%

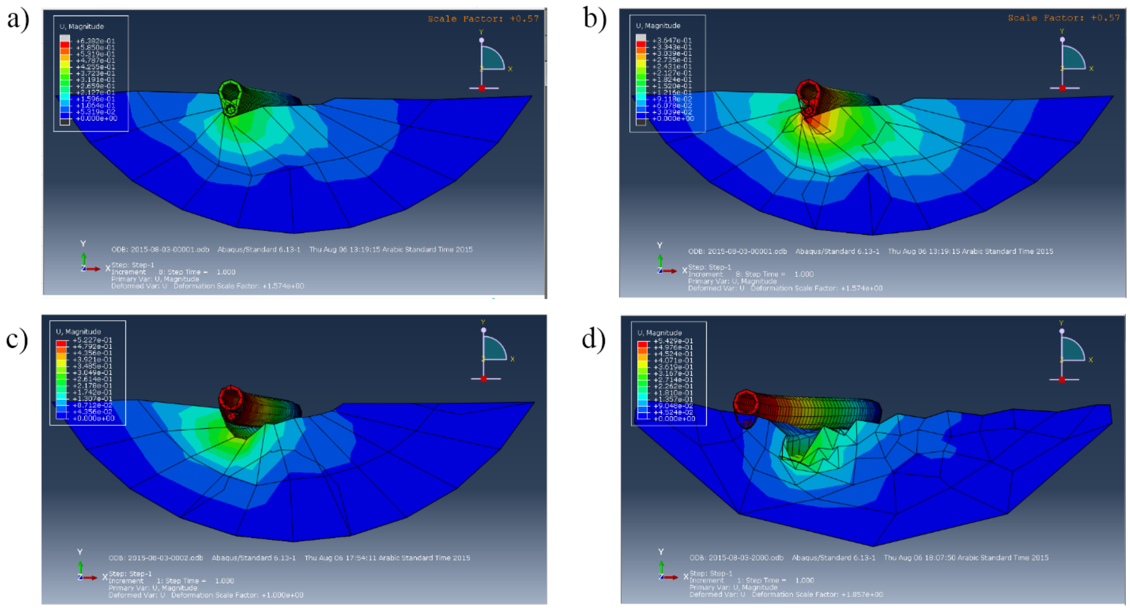

FIGURE 4.1: NMP-SEABED INTERACTION SIMULATIONS OF 40 METER OF NMP

Figure 4.1 a) and b) shows hydrodynamics effect after 10 years with a maximum of 0.3 meter for each 40 meter which equivalent to 3.34m per full 400m entire length. Figure 4.1 c) and d) shows the effect after 100 years of operation with an equivalent of 5.429m per full 400m entire length.

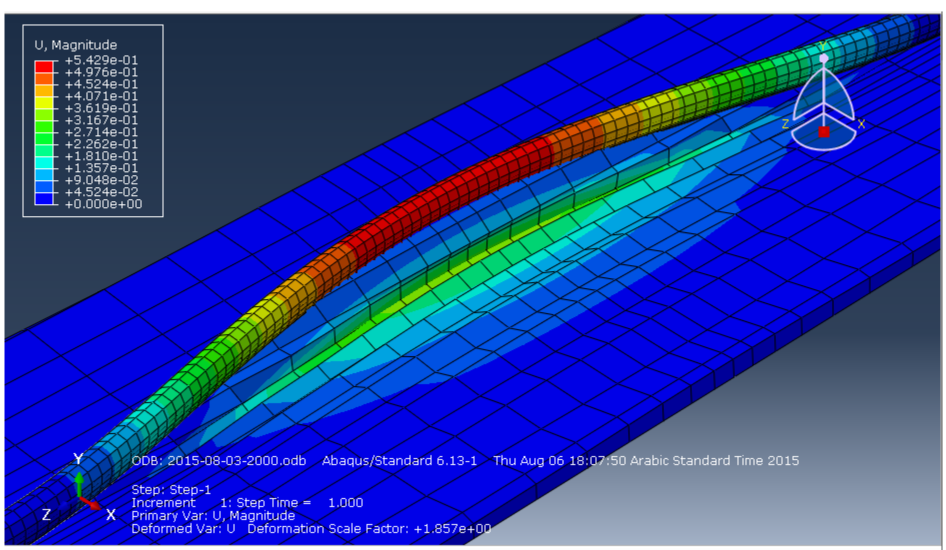

FIGURE 4.2: ISOMETRIC VIEW OF CHANGES ON DISPLACEMENT OF NMP

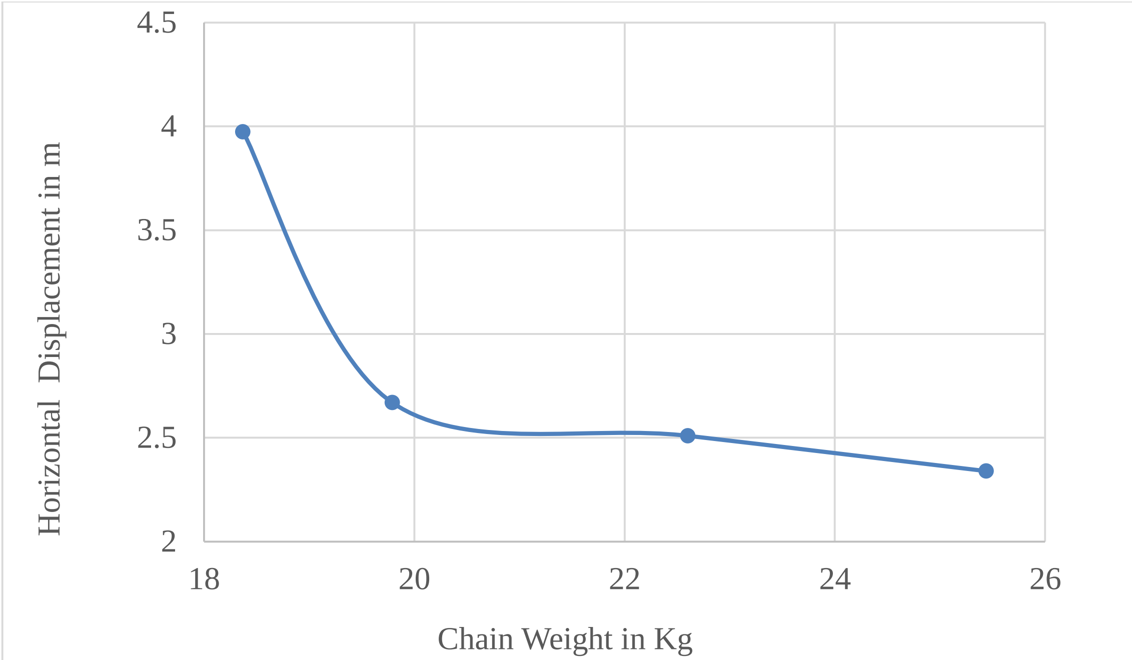

FIGURE 4.3: GRAPH OF HORIZONTAL DISPLACEMENT AGAINST ADDED WEIGHT

The result shows that with an increase of additional weight being applied, the higher the on-bottom stability of the pipe. Therefore, with the simulation we can estimate the weight in air needed for each Ball Socket Pipeline Jacket segment.

Using the data from Table 2.1 and Figure 4.3, it is safe to assume that the weight of BSPJ in seawater to be 34 kg.

TABLE 4.4: CHARACTERISTICS OF BALL SOCKET PIPELINE JACKET

Characteristics		**BSPJ**
Dimensions; ID: 206 mm, and OD: 292.92 mm		**Total (10 Segments)**
BSPJ volume, V_{BSPJ}	From SolidWorks Design	30002084.82 cubic millimetres ≈ 30 L
Weight in seawater, $W_{BSPJ,Sea}$	Weight for on-bottom stabilization	34 kg
Buoyancy	$V_{BSPJ} \times \rho_{seawater}$	30.75 kg
Empty weight in air, $W_{BSPJ,Air}$	$W_{BSPJ,Sea}$ + (Buoyancy/10 segments)	37.075 kg
Density of BSPJ, ρ_{BSPJ}	$W_{BSPJ,Air} / V_{BSPJ}$	1235.8 kg/m^3

TABLE 4.5: VALUES FOR ABAQUS SIMULATION

Item	**Values**
Inertial Force (Gravity)	98.1 N
NMP Uplifting Force	180 N
NMP Density	1693
NMP Young's Modulus	1.1E9 N/m^3
NMP Poisson's Ratio	0.4
BSPJ Uplifting Force	307.5 N
BSPJ Young's Modulus	150E9 N/m^3
BSPJ Poisson's Ratio	0.25
Boundary Conditions	PINNED at both ends of NMP
Interactions	• Ball to Socket • BSPJ to NMP

TABLE 4.6: FIXED VALUES TO USE IN ABAQUS

Density of Seawater, $\rho_{seawater}$	1.025 kg/L
Conversion factor (1 kg/m^3)	0.001 kg/L
Gravity	9.81 m/s^2
Clearance of Ball-Socket and BSPJ-NMP	5 mm

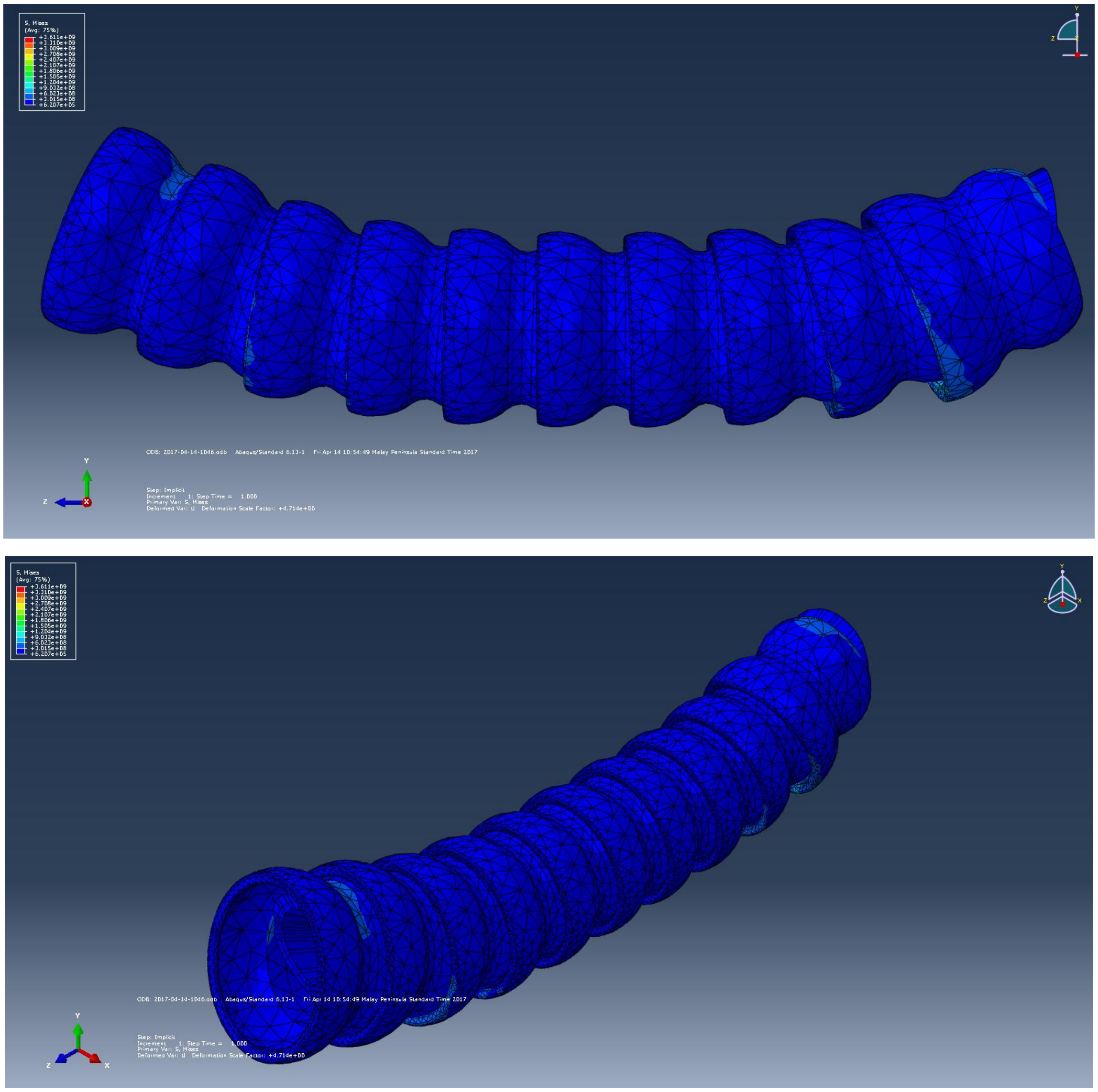

FIGURE 4.4: SIMULATION RESULT WITH BALL-SOCKET INTERACTION AND BSPJ-NMP INTERACTION UNDER INERTIAL AND LIFTING FORCES

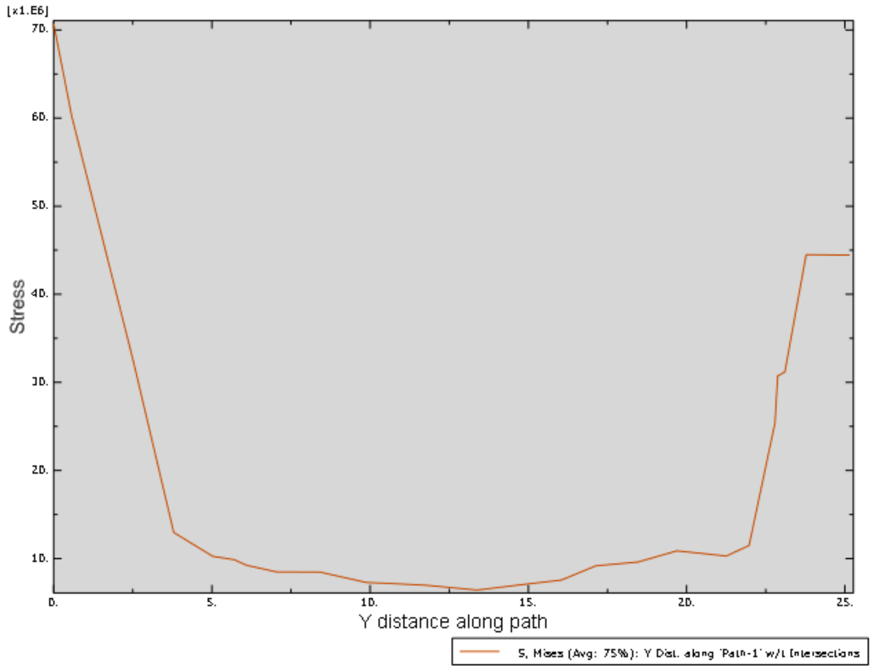

FIGURE 4.5: STRESS AGAINST Y DISTANCE ALONG PATH OF NMP

Figure 4.6 below shows the interaction of heavy-laden BSPJ at 7000 kg/m^3 density on Non-Metallic Pipe.

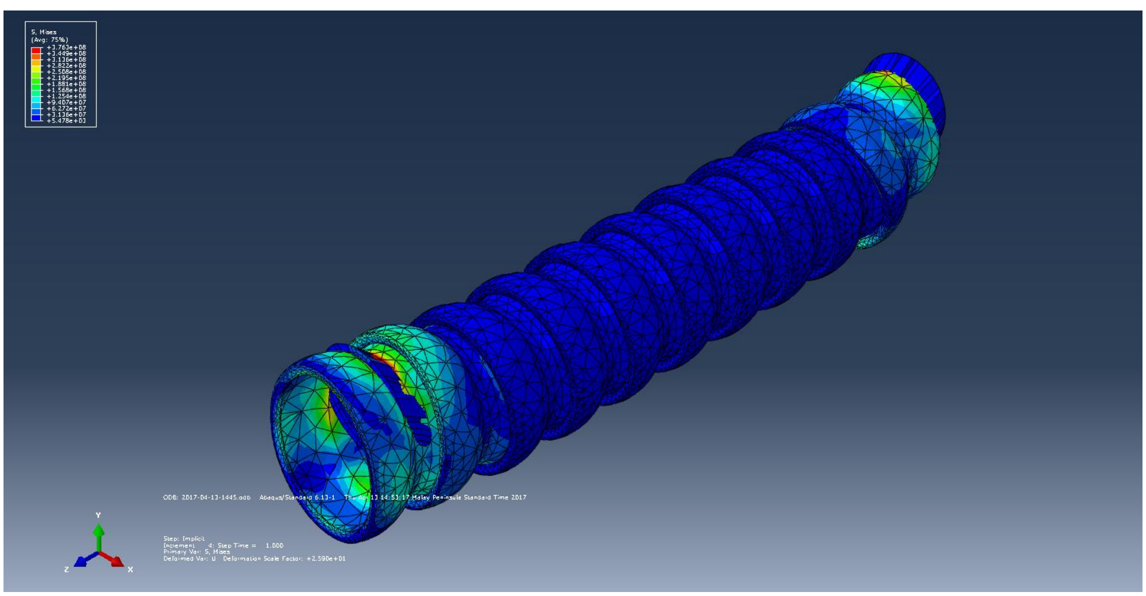

FIGURE 4.6: EFFECT OF HEAVY-LADEN BSPJ

The forces on a 2-D plane as shown in Figure 4.4, illustrates that the Ball Socket Pipeline Jacket (BSPJ) retains its locking mechanism and does not detach from one another while protecting the Non-Metallic Pipe from over-bending.

In another simulation, with heavy-laden BSPJ that contains heavy filler as shown in Figure 4.6, the BSPJ has an almost similar stress value of 1.761E08 compared to the normal condition which has 1.611E09.

The BSPJ design concept, incorporate encapsulated banding or protection to reduce installation time and providing ultimate abrasion resistant. As well as providing regulation clearance between flow-lines and pipelines crossings without the need for costly steel structures, concrete mattress or rock dumping.

On another note, due to higher levels of economic growth in Far East, the global requirement for electricity, internet data, fresh water, oil and gas transfer through the sea are increased. Therefore, the necessity for transfer networks to run through ever harsher deep water environments and the demand for highly advanced flow-line protection grows. Ball Socket Pipeline Jacket (BSPJ) is a protection system designed and developed to protect fibre optic cables, power cables, umbilical, flexible flow-lines, rigid flow-lines, hoses, and bundled products from abrasion and impact of drooped objects. The said BSPJ can also be used to add ballast to cables and flow-lines for hydrodynamic and on-bottom stabilization purposes. Establishing an enviable reputation as an industrial standard for subsea cable and flow-line protection systems.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

This project will pilot the commercialization of Ball Socket Pipeline Jacket through simulation and thorough testing of the prototype which could significantly reduce cost of providing a protective system on onshore and offshore pipelines. Simulation with computer-aided software e.g. ABAQUS and SolidWorks will provide the necessary data in order to analyse the efficiency of the system with evident results. An economic analysis on the demand, size and opportunity of the market will be conducted to provide the best approach for production and commercialization of the system which would yield the highest value and growth.

All in all, we have modelled a new optimised design for the BSPJ that could potentially reduce installation time. The new Ball Socket Pipeline Jacket design have an entry to slot for the pipe which will then be assembled and become a protective jacket for the pipeline.

The simulations provide clear data that the BSPJ can withstand nearly seven times its original density and still remains solid in protecting the pipeline without detaching by itself on account of the locking mechanism of the ball and socket joints.

With the fabricated BSPJ, we can make non-destructive testing and destructive testing under scrutinizing conditions that would determine the performance of BSPJ mechanically. At the same time, numerical simulation using ABAQUS software could be done to model the interaction of BSPJ against the seabed and underwater current forces.

Therefore, BSPJ is

i. Improving pipeline on-bottom stability.
ii. Protecting from drop objects.
iii. Shielding subsea bundled products reducing soil/solid interaction effect.
iv. The said system could incorporate stinger compatibility for advanced VIV suppression solutions.
v. The BSPJ provide thermal insulation, corrosion resistant banding suitable for a wide range of on and offshore applications.

The project can be further researched by making extensive simulations using the equations as stated in Chapter 2.6 as well as doing experiments to test out the prototype that have been moulded in the BSPJ die. More research on the composition of the BSPJ composite could really assist in making a cost analysis of the whole BSPJ protective system. Furthermore, the need to have the base materials to make the composite should be considered in order to ease the mixing procedure. Other than that, a new design that could accommodate the heavy-laden filler in the BSPJ segments which would effectively increase the on-bottom stability as simulated in Chapter 4.1. Lastly, further research can be done to incorporate thermal insulation, stinger compatibility for advanced Vortex-induced Vibration suppression solution along with compatibilities for a wide range of onshore or offshore applications.

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The tables below show the timeline to ensure progress on the project throughout FYP 1 and FYP 2 courses respectively.

Table 1: Gantt Chart for FYP 1

No.	Detail Work	Week (2016)														
		September				October				November				December		
		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1.	Consolidation of FYP Titles															
2.	Approval of FYP Titles															
3.	Topic Assignments															
4.	Start the Project															
5.	Preliminary Research Work															
6.	Extended Proposal Writing															
7.	Submission of Extended Proposal					•										
8.	Proposal Defence															
9.	Product Benchmarking															
10.	Analysis Data Collection															
11.	Pre-Interim Report Writing															
12.	Die 3D Design															
13.	Submission Pre-Interim Report													•		
14.	Update Report with Progress															
15.	Submission of Interim Report															•

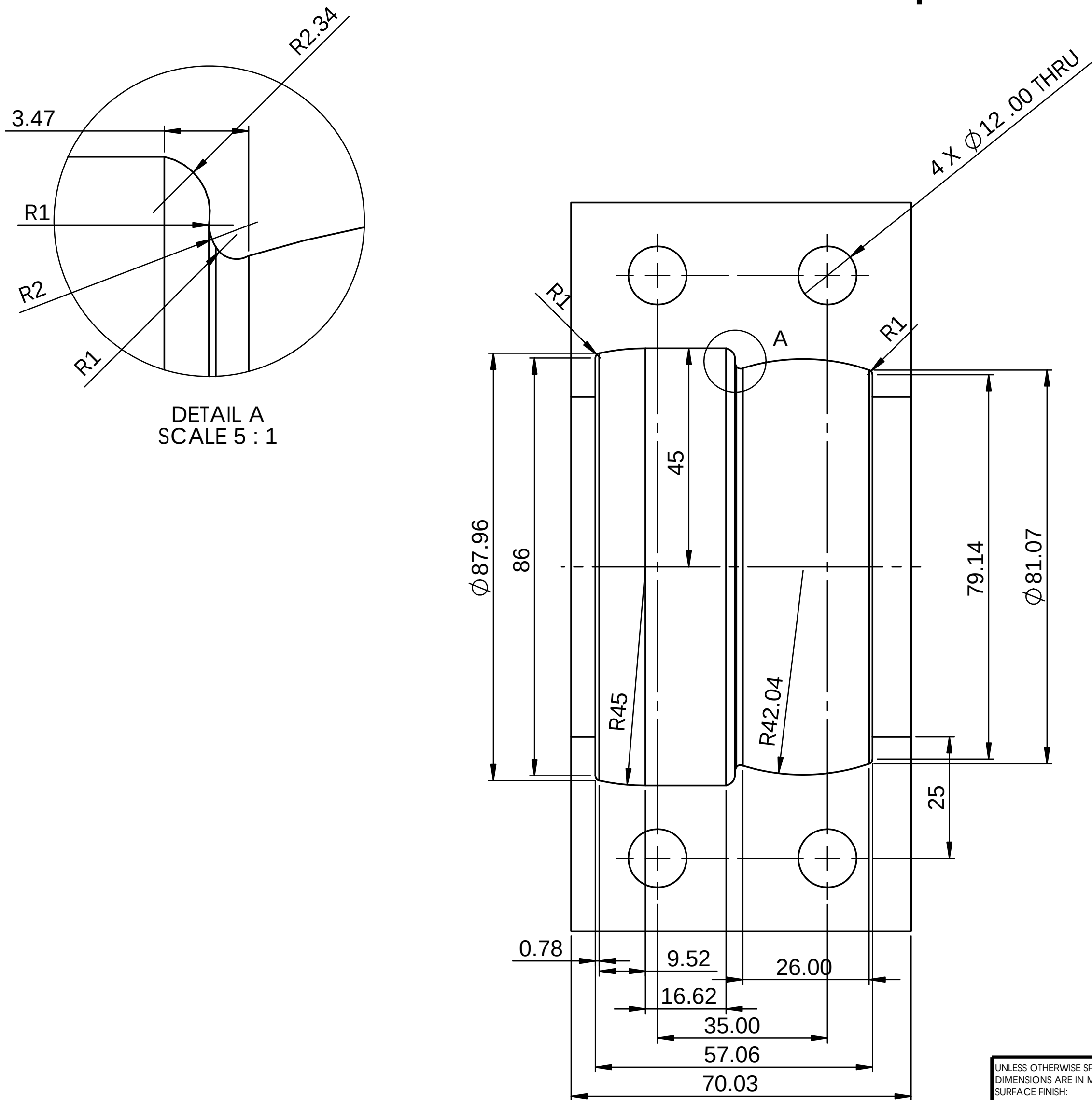
- Suggested Milestone

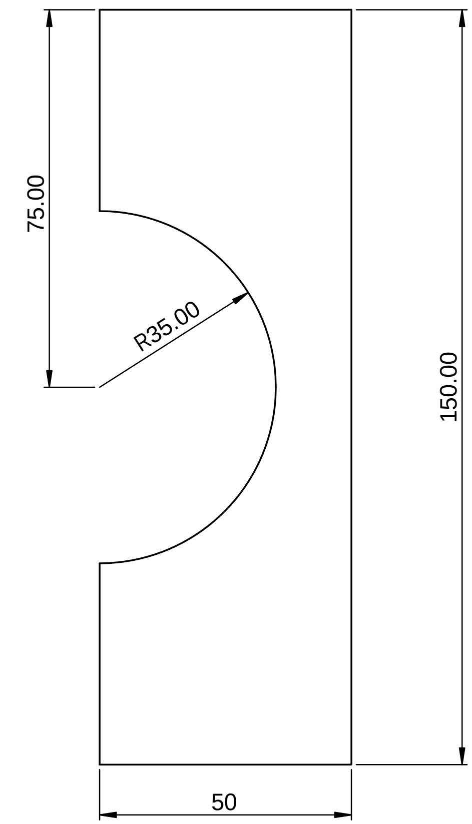
Process

Table 2: Gantt Chart for FYP 2

No.	Detail Work	Week (2017)														
		January		February				March					April			
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1.	Prototype Fabrication Update	■														
2.	Prototype Testing (NDT)		■	■												
3.	Prototype Testing (DT)		■	■												
4.	Data Analysis		■	■	■	■										
5.	Thesis Writing			■	■	■	■									
6.	Validation of Result					■	■									
7.	Submission of Progress Report							●								
8.	Thesis Writing Continues							■	■	■						
9.	Pre-SEDEX										●					
10.	Submission of Draft Final Report											●				
11.	Submission of Dissertation (softbound)												●			
12.	Submission of Technical Paper												●			
13.	Viva													●	■	
14.	Submission of Project Dissertation (hardbound)														■	●

- ● Suggested Milestone
- ■ Process





UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBURR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION C

	NAME	SIGNATURE	DATE
DRAWN	ARIF NASRUDIN		26 JAN 17
CHK'D	DR. DHER		3 FEB 17
APPV'D	DR. DHER		3 FEB 17
MFG			
Q.A			

MATERIAL:

WEIGHT:

TITLE:

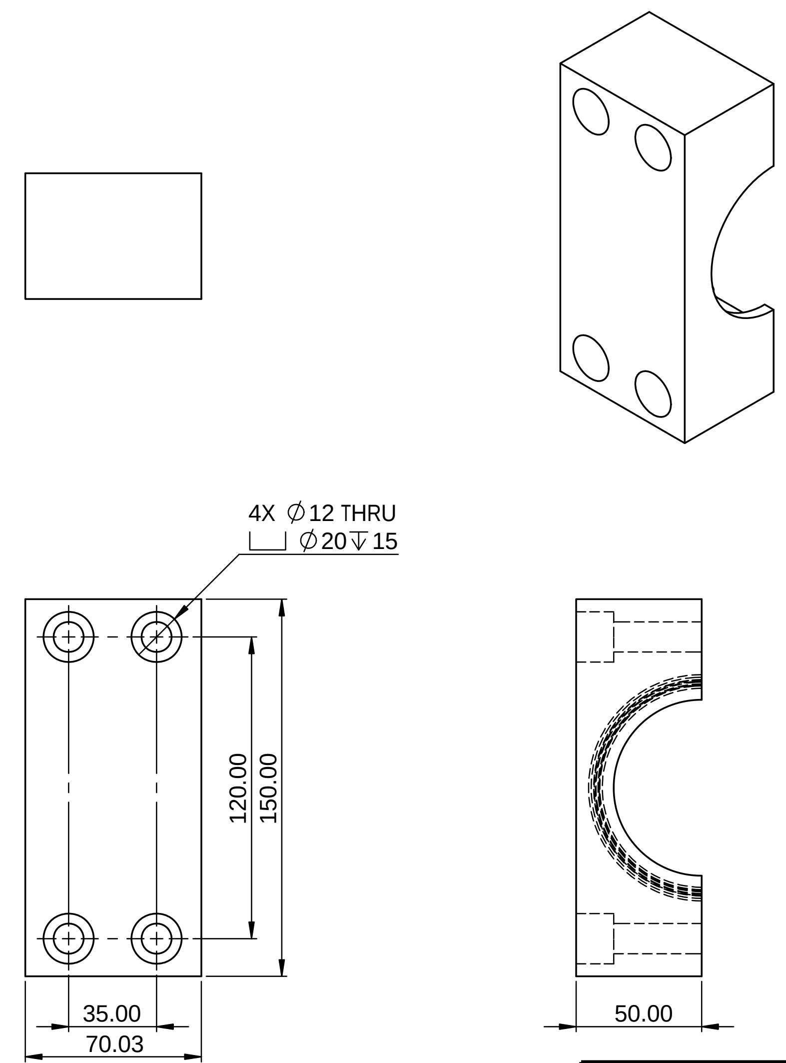
BSPJ Female

DWG NO.
P001-2017-23-1700-BSPJ Female

A3

SCALE:1:1

SHEET 1 OF 2



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBURR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION C

	NAME	SIGNATURE	DATE
DRAWN	ARIF NASRUDIN		26 JAN 17
CHK'D	DR. DHER		3 FEB 17
APPV'D	DR. DHER		3 FEB 17
MFG			
Q.A			

MATERIAL:

WEIGHT:

TITLE:

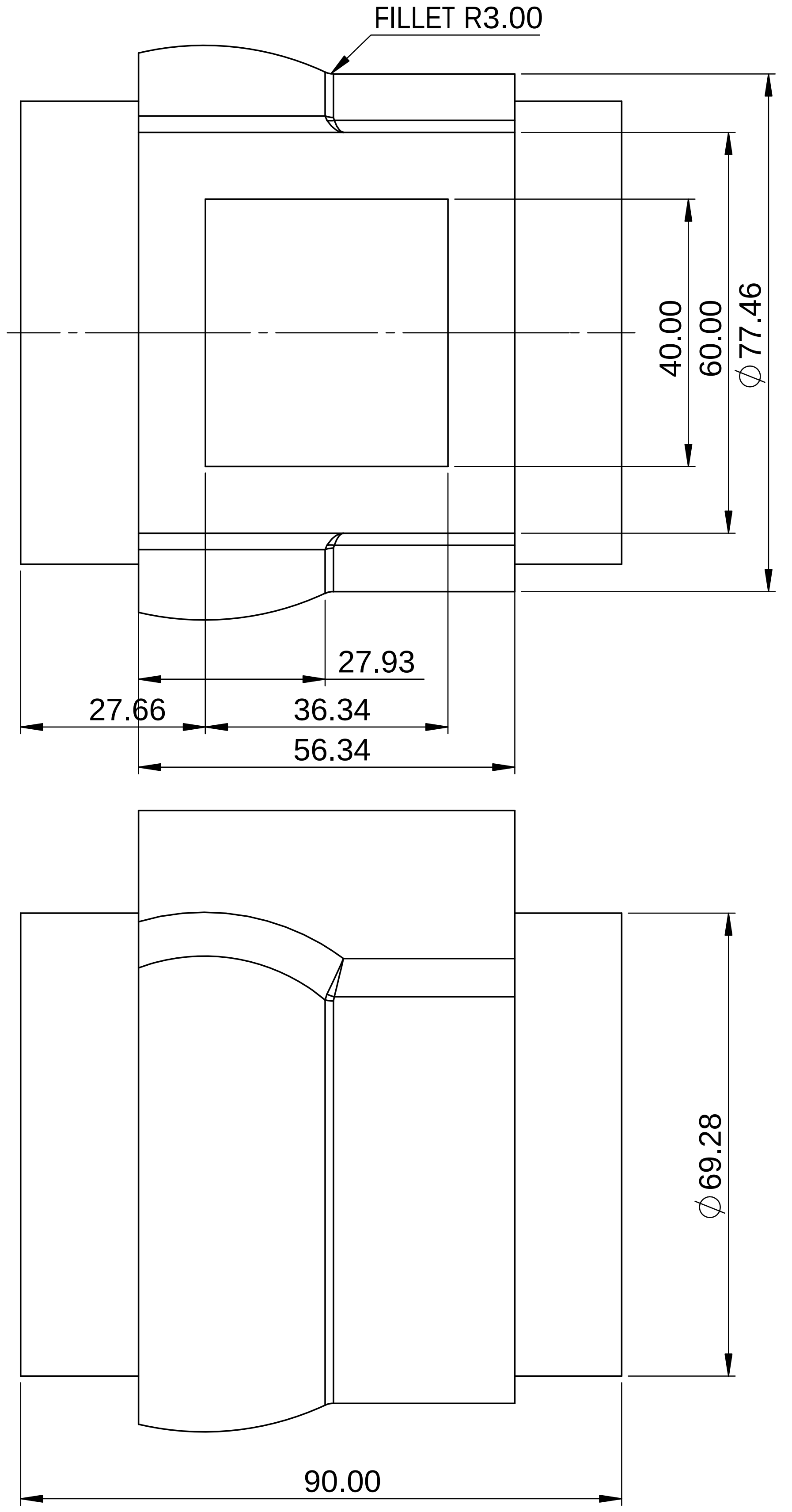
BSPJ Female

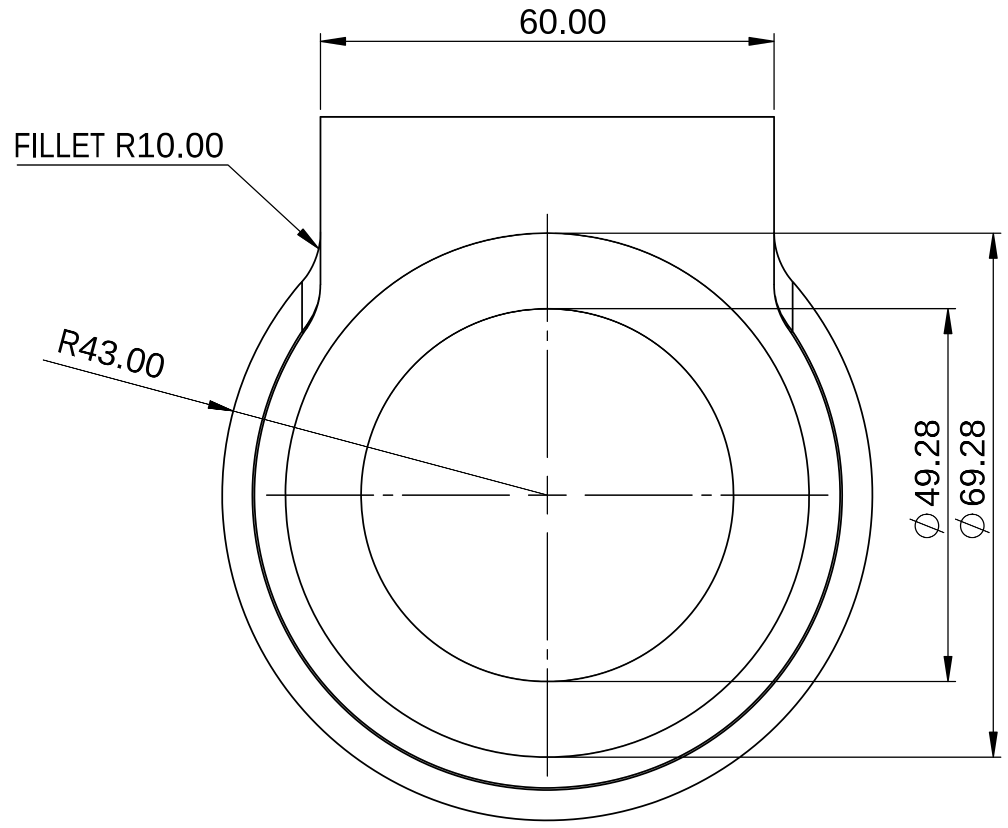
DWG NO.
P001-2017-23-1700-BSPJ Female

A3

SCALE:1:1

SHEET 2 OF 2





UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBURR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE
DRAWN	ARIF NASRUDIN		1 FEB 17
CHK'D	DR. DHER		3 FEB 17
APPV'D	DR. DHER		3 FEB 17
MFG			
Q.A			

TITLE:

BSPJ Male

MATERIAL:

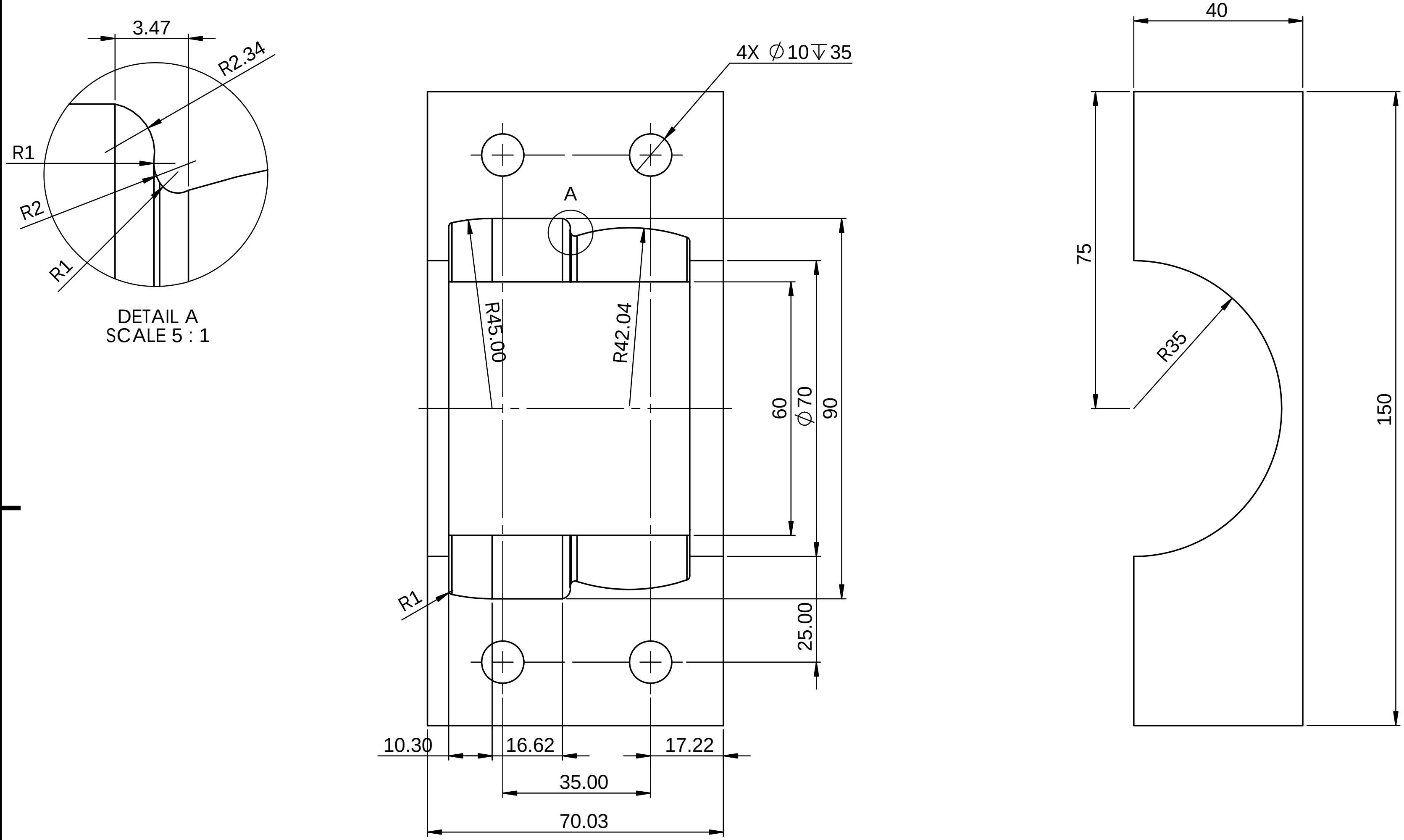
DWG NO.
P002-2017-02-02-1000-BSPJ Male

A3

WEIGHT:

SCALE:1:1

SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBURR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION C

	NAME	SIGNATURE	DATE
DRAWN	ARIF NASRUDIN		26 JAN 17
CHK'D	DR. DHER		3 FEB 17
APPV'D	DR. DHER		3 FEB 17
MFG			
Q.A			

MATERIAL:

WEIGHT:

TITLE:

BSPJ Female External

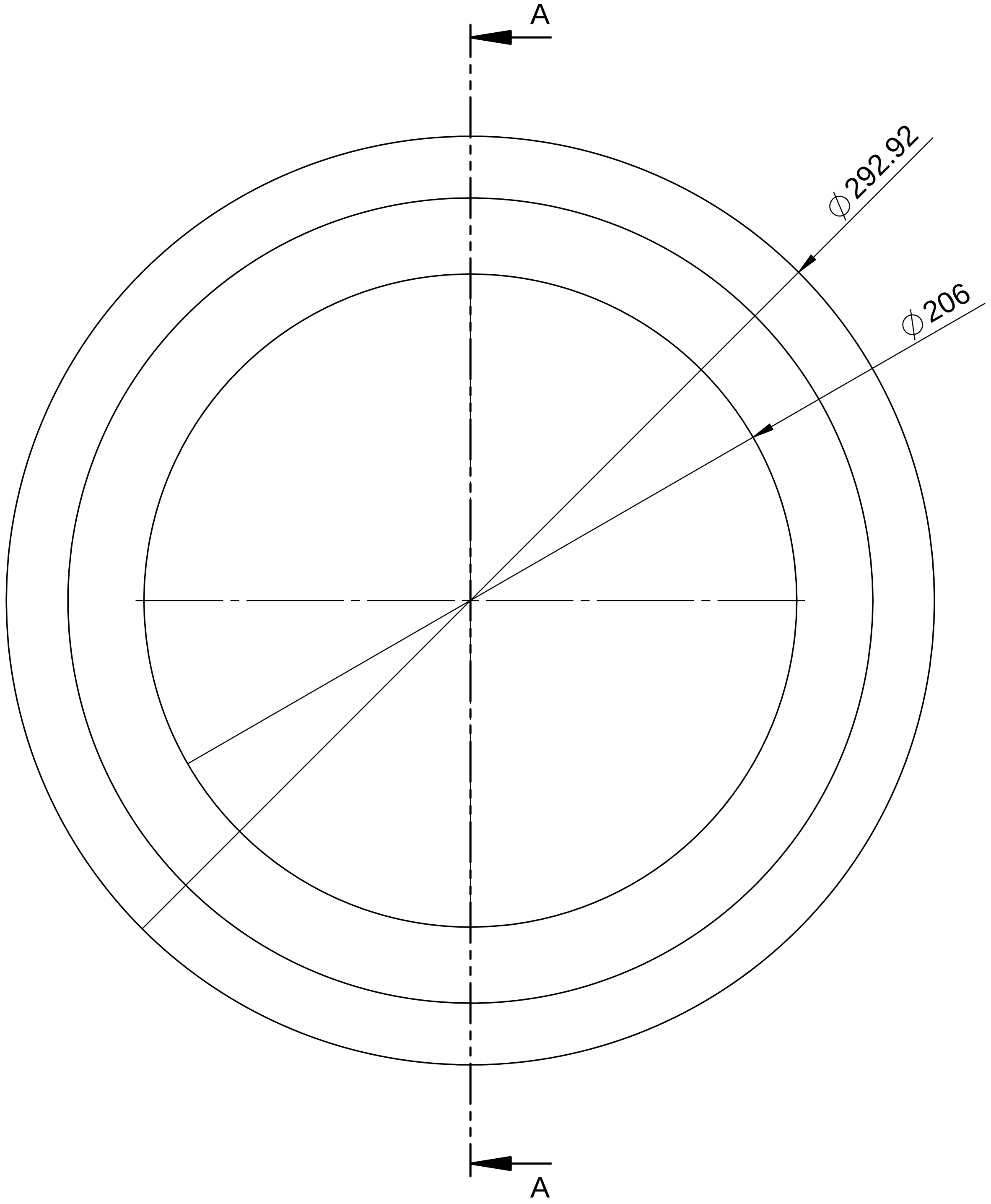
DWG NO.

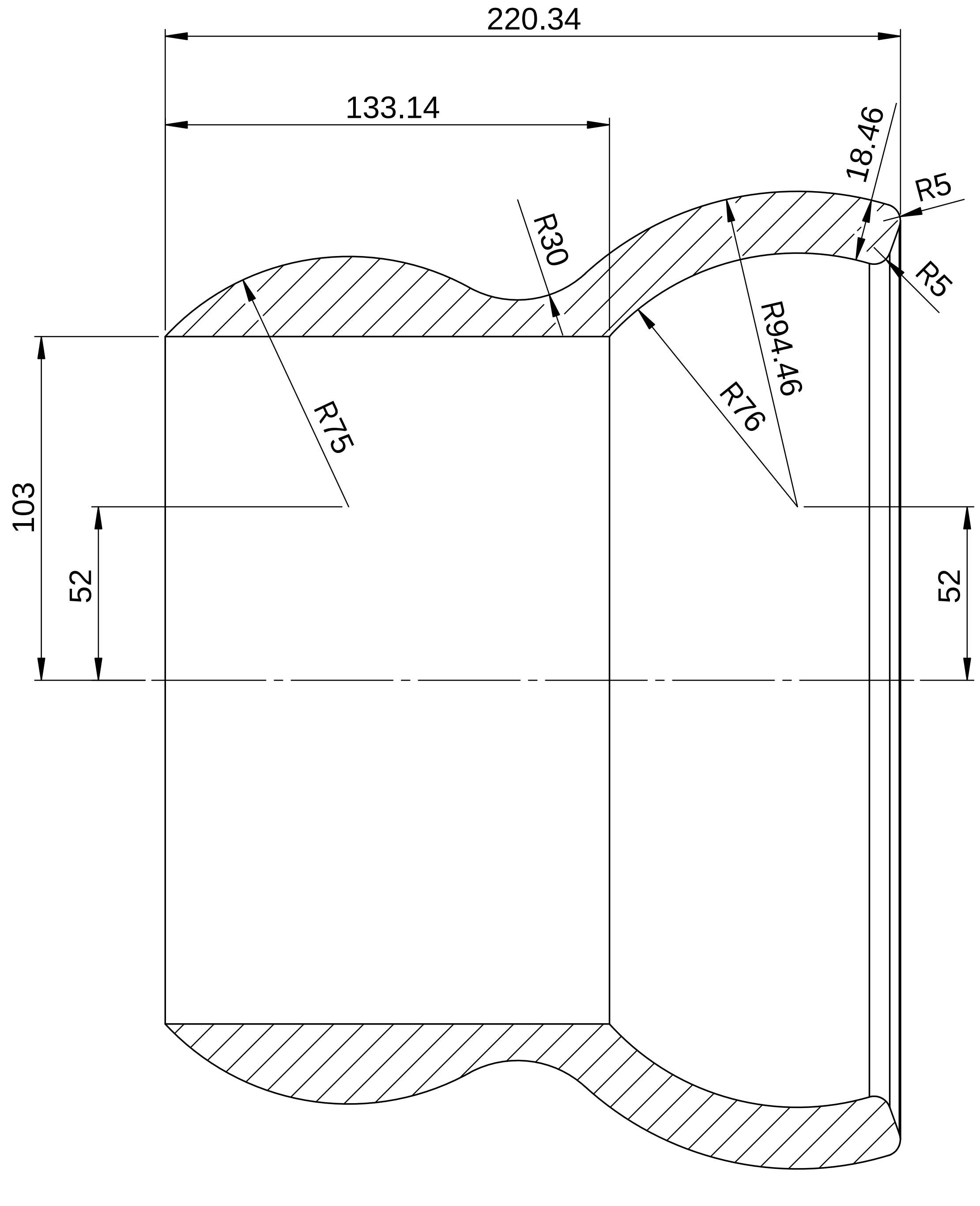
P003-2017-02-02-1000-BSPJ Female External

A3

SCALE:1:1

SHEET 1 OF 1





SECTION A-A
SCALE 1 : 2

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBURR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION A

	NAME	SIGNATURE	DATE
DRAWN	ARIF NASRUDIN		12 APR 17
CHK'D	DR DHER		12 APR 17
APPV'D			
MFG			
Q.A			

MATERIAL:

WEIGHT:

TITLE:

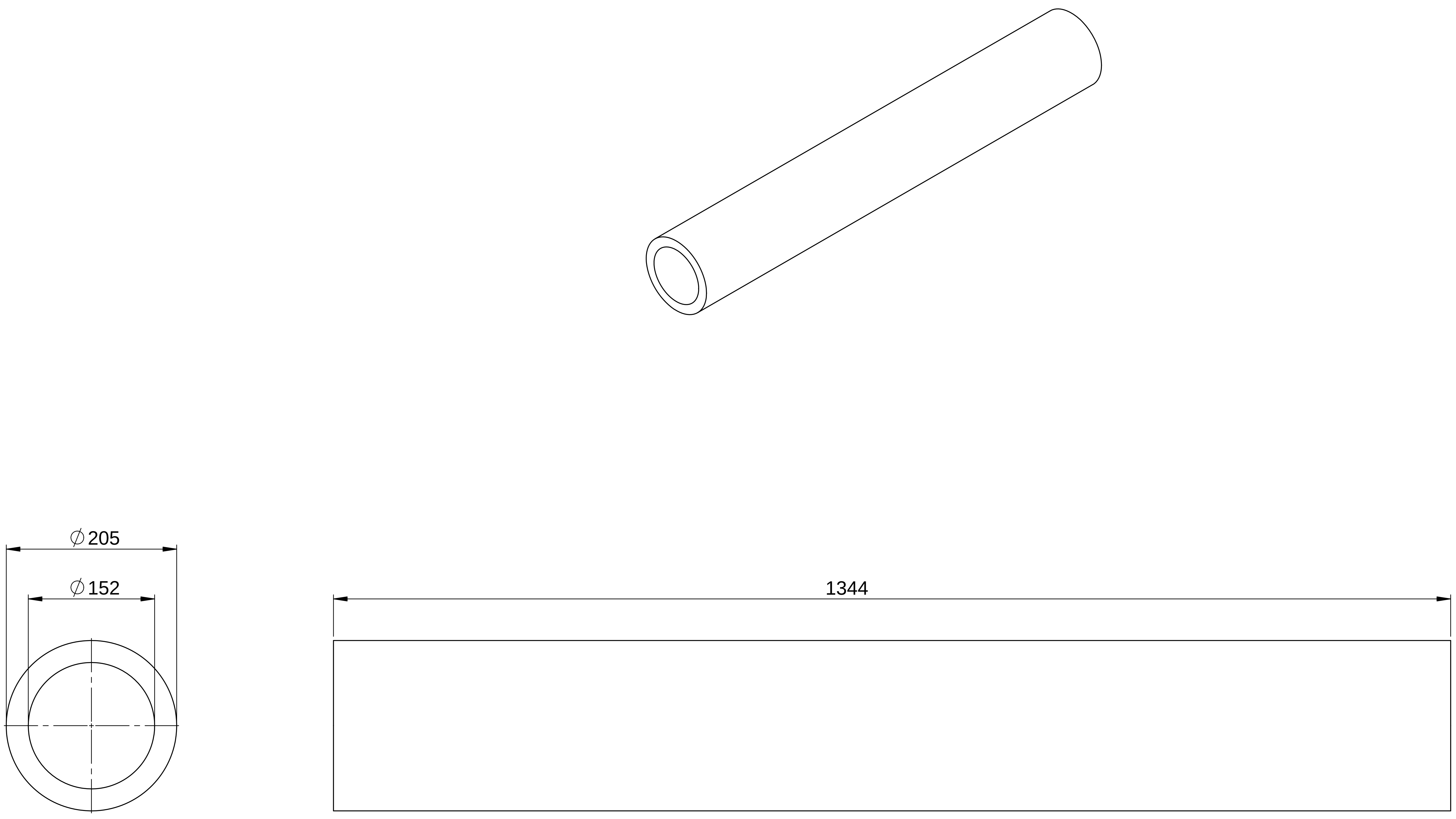
BSPJ Segment

DWG NO.
P004-2017-04-12-1751-Segment BSPJ

A3

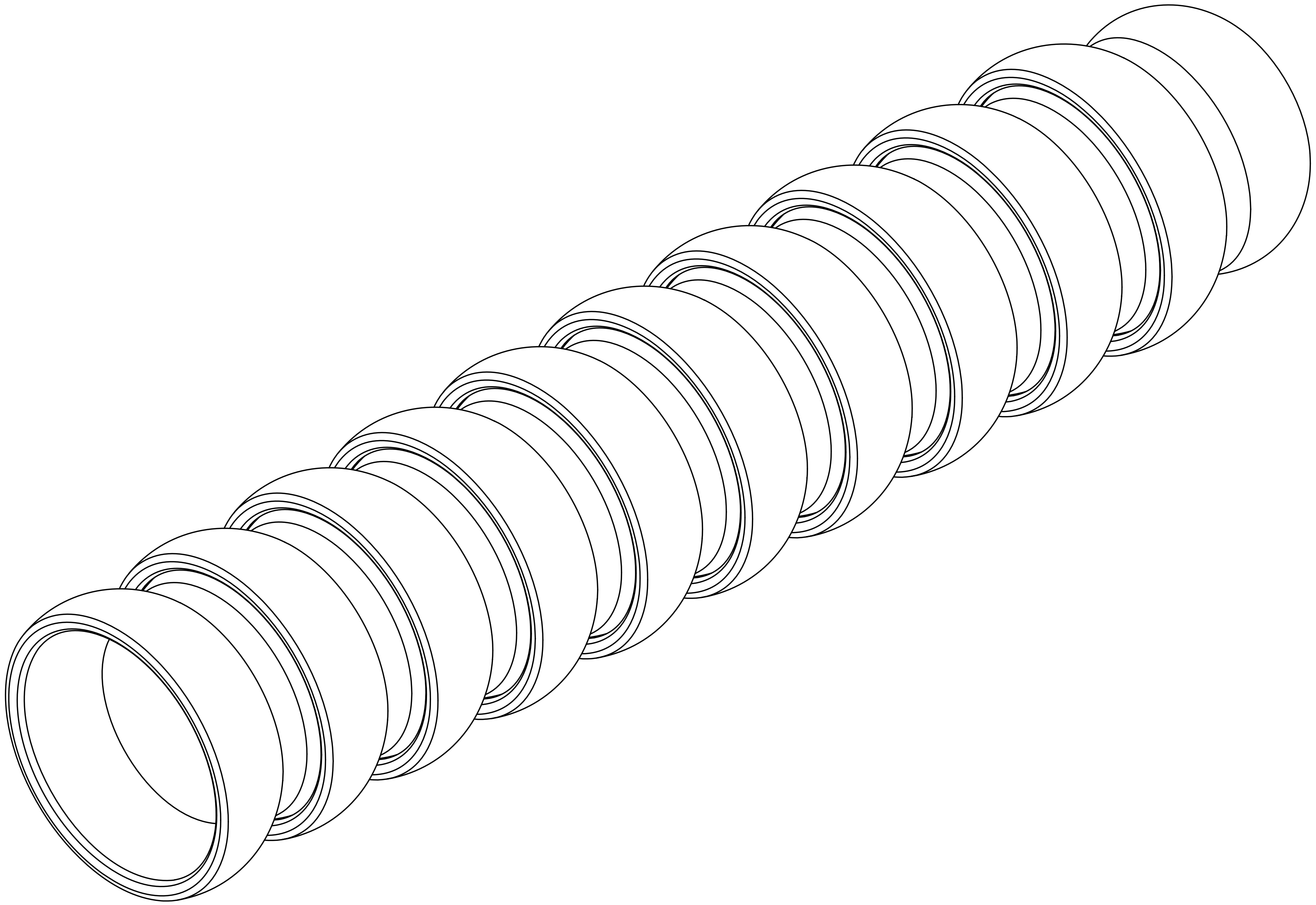
SCALE:1:2

SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:		FINISH:			DEBURR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION A
	NAME	SIGNATURE	DATE			TITLE:	
DRAWN	ARIF NASRUDIN		12 APR 17			NMP	
CHK'D	DR DHER		12 APR 17				
APPV'D							
MFG							
Q.A				MATERIAL:		DWG NO. P004-2017-04-12-1800-NMP	A3
				WEIGHT:		SCALE:1:5	SHEET 1 OF 1

8 7 6 5 4 3 2 1



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBURR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION A

	NAME	SIGNATURE	DATE
DRAWN	ARIF NASRUDIN		12 APR 17
CHK'D	DR. DHER		12 APR 17
APPV'D			
MFG			
Q.A			

TITLE:

BSPJ 10 SEGMENTS

MATERIAL:

DWG NO.
P004-2017-04-12-1800-BSPJ

A3

WEIGHT:

SCALE:1:5

SHEET 1 OF 1

8 7 6 5 4 3 2 1

Mass properties of P004-2017-03-21-1700-10in BSPJ

Configuration: Default

Coordinate system: -- default --

Mass (user-overridden) = 340000.00 grams

Volume = 30002084.82 cubic millimeters

Surface area = 3598294.36 square millimeters

Center of mass: (millimeters)

X = 0.00

Y = 0.00

Z = 533.30

Principal axes of inertia and principal moments of inertia: (grams * square millimeters)

Taken at the center of mass.

Ix = (0.00, 0.00, 1.00) Px = 5099424284.12

Iy = (0.00, -1.00, 0.00) Py = 54577526223.90

Iz = (1.00, 0.00, 0.00) Pz = 54577526223.90

Moments of inertia: (grams * square millimeters)

Taken at the center of mass and aligned with the output coordinate system.

Lxx = 54577526223.90 Lxy = 0.00 Lxz = 0.00

Lyx = 0.00 Lyy = 54577526223.90 Lyz = 0.00

Lzx = 0.00 Lzy = 0.00 Lzz = 5099424284.12

Moments of inertia: (grams * square millimeters)

Taken at the output coordinate system.

Ixx = 151275242704.70 Ixy = 0.00 Ixz = 0.00

Iyx = 0.00 Iyy = 151275242704.70 Iyz = 0.00

Izx = 0.00 Izy = 0.00 Izz = 5099424284.12