UNIVERSITY OF TWENTE-ALLSEAS ENGINEERING BV

Internship Report

Concept design of tracked stinger roller box

Yuhan Luo (Student No:1538276)

Supervised by: Prof. Dr. Ir. Andre de Boer (University of Twente)
Ir. Martin Esselbrugge (Allseas Engineering B.V.)
Ir. Alexander Huisman (Allseas Engineering B.V.)

November 2015

Allseas

UNIVERSITY OF TWENTE.

Table of Contents

ACKNOWLEDGEMENT

This document is written as an internship report for the master study Mechanical Engineering of the University of Twente in Enschede. The report has been carried out in the Innovations department of the company Allseas Engineering B.V., located in Enschede.

This internship would not have been completed without help and support of many people. First of all I would like to thank prof. dr. ir. A. de Boer for his support to perform my internship at Allseas Engineering B.V.

I am grateful that Martin Esselbrugge and Alexander Huisman gave me the opportunity to perform my project in Allseas Engineering B.V.and provided me great patience and support during the internship.

At last, I would like to express my thanks to all the colleagues for their support during my internship. I really enjoyed the days working at Allseas.

Yuhan Luo
30/11/2015

DEFINITION OF COORDINATE SYSTEM

Definition of coordinate system is shown in Figure 0-1 and defined in the following way:

- X axis: longitudinal direction and tangential to the stinger
- Y axis: horizontal direction, perpendicular to the stinger
- Z axis: vertical direction to the stinger

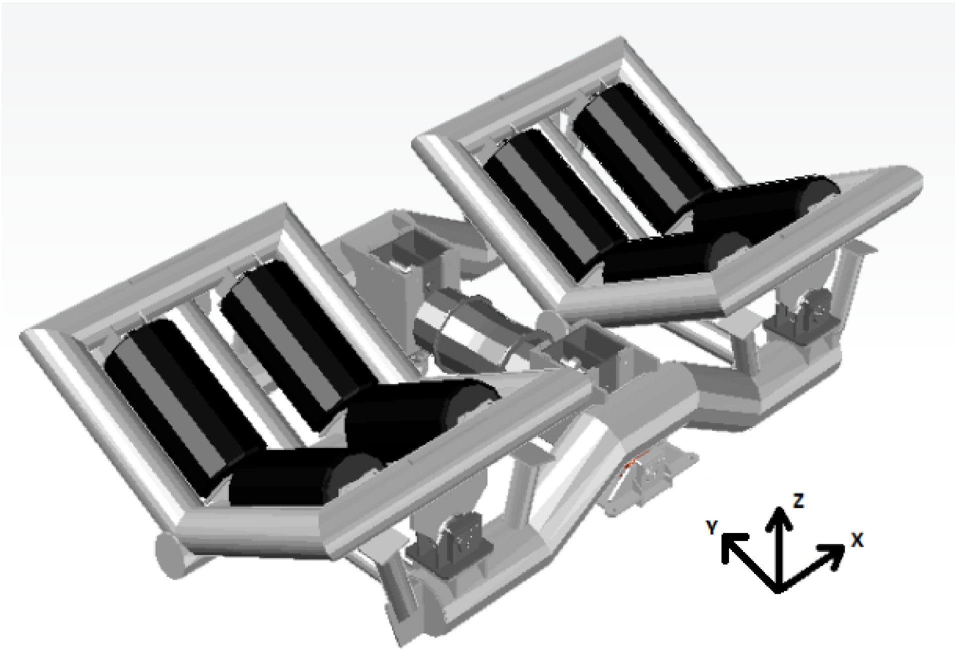

Figure 0-1 Coordinate system

Unless stated, the above mentioned coordinate system should be used.

1. INTRODUCTION

1.1 Allseas Group

The Swiss-based Allseas Group is one of the most famous offshore companies in the world. The company is a global leader in subsea constructions and offshore pipelay and is headed by Edward Heerema. Founded in 1985, Allseas has over 2500 employees, with main offices in Delft, Essen, London, Funchal, Houston, Perth, Mumbai and its head-office in Switzerland.

The head office locates in Delft and is dedicated to project preparation, technical supports and project management for other departments of Allseas Group. Allseas Engineering B.V. consists of several apartments including Innovation Department which is responsible for research and design tasks. This internship has been performed in this department.

Currently, Allseas owns five pipelay vessels and two service vessels. The pipelay vessels are named *Pioneering Sprit, Solitaire, Audacia, Lorelay and Tog Mor*. Together, they have completed over 240 projects for clients from all over the world and installed nearly 18,000 kilometre of pipes [1]. Allseas does not limited itself to existing technology, new techniques and solutions are explored whenever needed.

Figure 1-1 Allseas vessels

1.2 Pipelay methods

Three pipelay methods, S-lay, J-lay and reeling-lay, are commonly used. S-lay is used by Allseas for all the vessels.

S-lay is a method where 12 m sections of pipe are welded in to the pipeline on a horizontal production line and the pipeline follows an S-shaped path from the end of vessel to the seabed. A tensioner system in the production line applies axial force to the pipeline to prevent buckling of the pipeline. See Figure 1-2 for an overview of S-lay pipelay method.

The horizontal production line is called a firing line on Allseas' pipelay vessel. When the pipe has left the end of the firing line, it is guided by a stinger. The stinger is set to a radius depending on water depth and pipe diameter. The pipe follows the pre-determined path to prevent bucking. The inflection point where the curvature of the pipe is zero divides a pipe into two parts, the overbend and the sagbend, as shown in Figure 1-2. The pipe is supported by roller boxes which are installed on the stinger. The sagbend is the part between the inflection point and the touchdown point at the seabed.

In order to install pipelines of various diameters and in different waters, the radius of the stinger must be adjustable. Therefore, the stinger sections are designed to rotate relative to each other and the roller boxes are adjustable in height.

In normal operation condition, the pipeline is not allowed to touch the last roller box. If this happens, the offset between the singer and the pipe is quite large. The curvature of the pipeline may be larger than expected. As a result, pipeline buckling may occur.

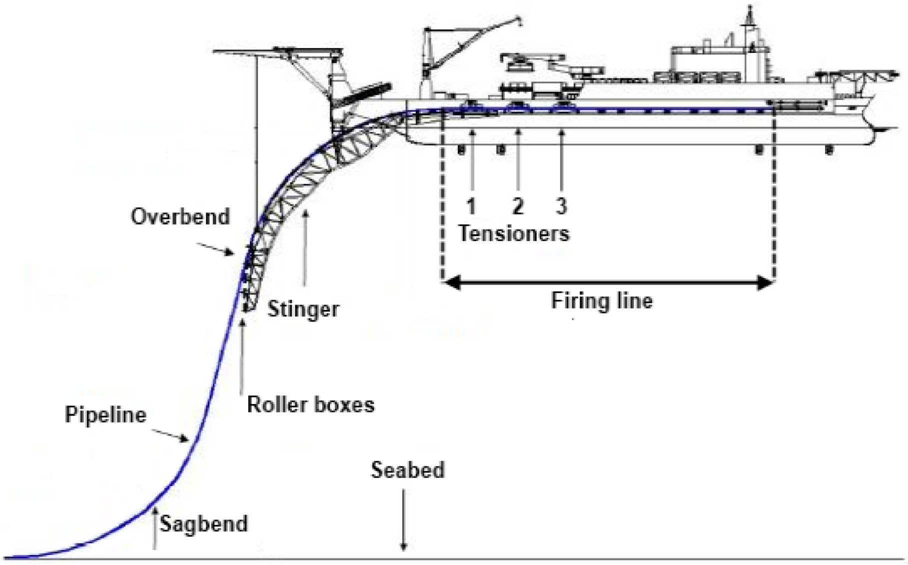

Figure 1-2 S-lay pipelay method and terminology

1.3 Solitaire's roller box

1.3.1 General

Since this project focuses on the roller box of *Solitaire*, the roller box system of *Solitaire* is introduced in this part. Roller box systems on other vessels of Allseas are based on the same principle but different in details.

The new stinger installed on *Solitaire* in 2010 consists of 3 sections. The stinger sections are able to rotate to change the radius of stinger. The radius ranges from 80 m to 350 m.

The *Solitaire* stinger is equipped with 17 roller boxes divided into six types. The centre to centre distance between roller boxes is around 9 m and may change a bit when the radius of stinger changes. The existing roller box system is adjustable in height and has free rotational degrees of freedom around the Y axes. One of the six types is called double seesaw roller box. Technical drawings are presented in Appendix A.

Roller boxes are installed on the top of stinger and directly support the pipe. Figure 1-3 shows a typical double seesaw roller box system. Main components and their functions are listed in Table 1.1.

Table 1.1 Main components and their functions of a seesaw roller box

Components	Functions
Roller	Support and guide the pipe directly Transfer loads to secondary frame
Secondary frame	Support the rollers Self-adapt to the pipelines Transfer loads to main frame
Main frame	Support the secondary frame Self-adapt to the pipelines Transfer loads to support beam
Support beam	Support the main frame Transfer loads to stanchions
Stanchion	Support the support beam Transfer loads to the stinger
Height adjustment system (including stanchions with holes, support beam and locking pins)	Fix roller boxes to a desired height with an increment of 10 mm

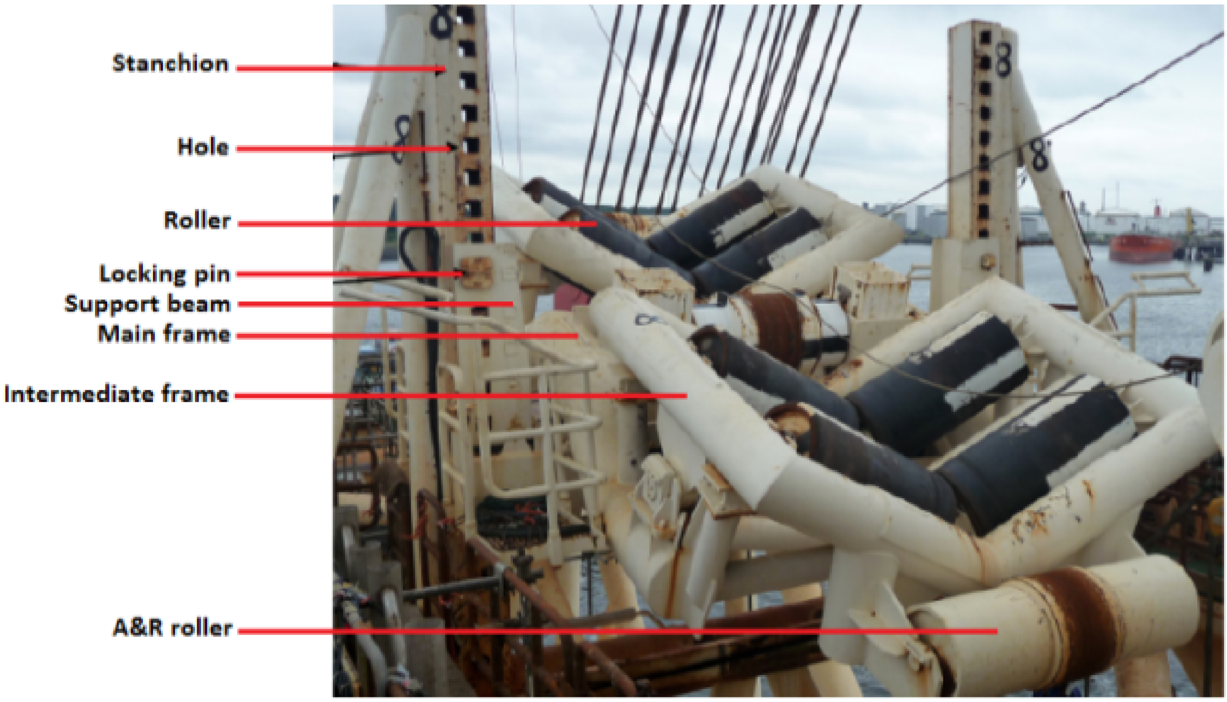

Figure 1-3 Double seesaw roller box and terminology

Other types of roller boxes have different numbers of rollers or do not have secondary frame. But each type has similar components compared to the seesaw roller box but different in sizes.

According to a thorough study on roller box loads with different stinger radii by the Department of Pipeline Engineering, the load cases are defined for *Solitaire* based on the following stinger radius representing deep, intermediate deep and shallow water cases, respectively:

- R=110m
- R=140m
- R=200m
- R=300m

The design loads include the design global roller box loads and design local roller box loads [2]. The design global roller box loads act on the stinger simultaneously. This is load capacity of the stinger. The design local roller box loads represent the load capacity of a single roller box.

1.3.2 Seesaw Roller Box Details

Main properties of seesaw roller box are shown in Table 1.2.

Table 1.2 Double seesaw roller box specifications

Property	Quantity
Length	6070 mm
Width	4600 mm
Secondary frame length	2000 mm
Secondary frame width	2800 mm
Number of supported rollers	8
Secondary frame form	V-shape of 30 with Y direction
Roller material	Steel
Roller diameter	508 mm
Coating material	Polyurethane(PU)
Coating thickness	38 mm

In Figure 1-3, the double seesaw roller box consists of two secondary frames. The seesaw mechanism works through two sub hinges and one main hinge which are shown in Figure 1-4. If there were 3 pairs of rollers on secondary frame, there should be 2 more hinges so that the whole system has enough degrees of freedom. Otherwise the rollers cannot all contact the pipeline.

The double seesaw roller box is able to follow the bending pipeline by forming a seesaw configuration according to the pipe load distribution. If the load on the front rollers is more than that on the back ones, the roller box goes down at the front and goes up at the back. The seesaw function works by force. When a regular pipeline moves over the stinger, the main hinge does not rotate and the sub hinges rotates by a small degree. When an irregular structure (anode, in line structure etc.) moves over the roller box, all the hinges would rotate by a larger degree [3].

The roller boxes suffer loads in X, Y and Z directions simultaneously. A V-shaped form of the secondary frame is designed to support the pipe movement in both vertical and transversal directions. The loads are directly applied on the rollers. The bearing capacities of the stinger rollers are different with variable thicknesses and steel core sizes [4]. Roller with a diameter of 508 mm and coating of 38 mm has a bearing capacity of 15 mT which is chosen for the current design.

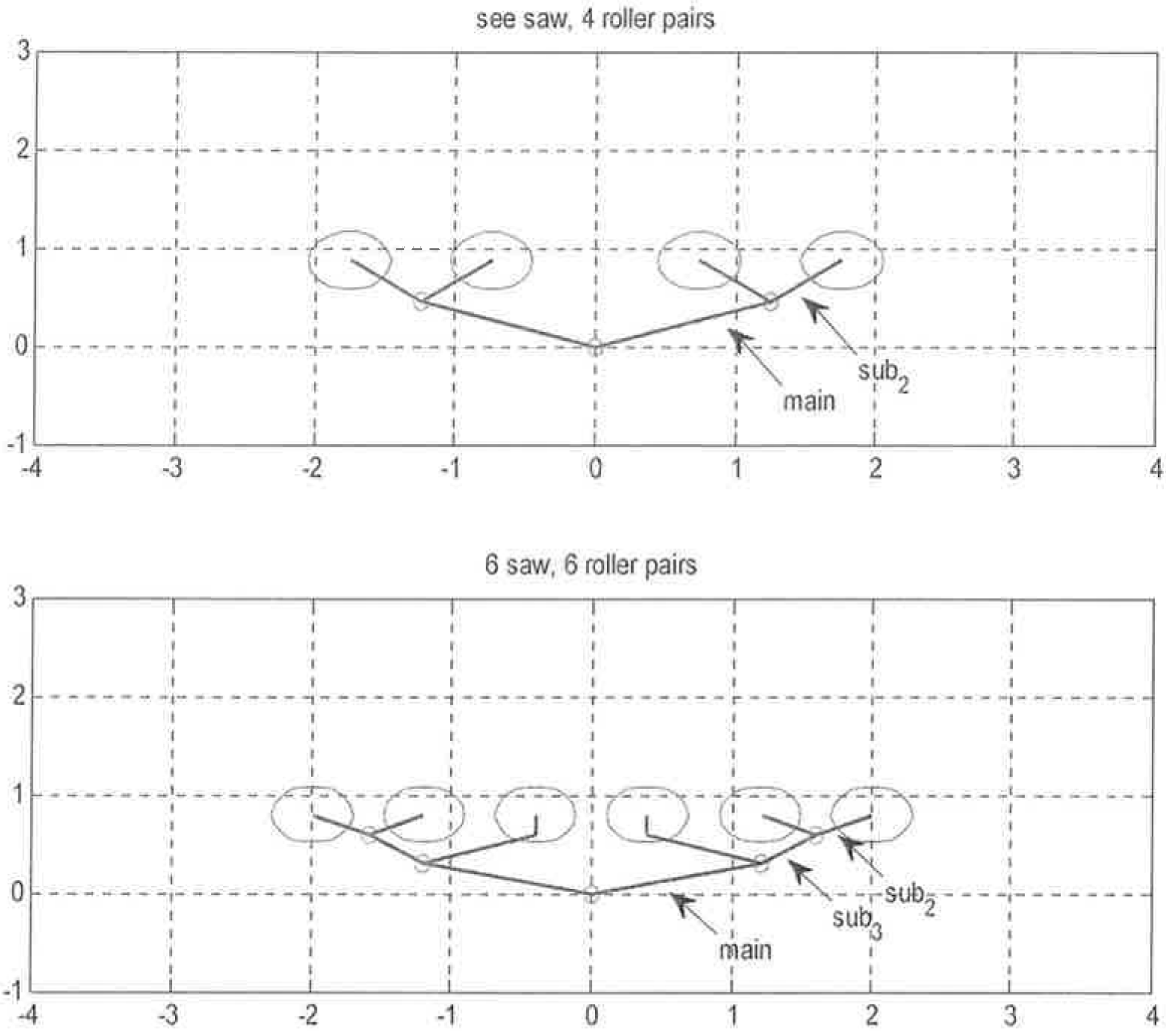

Figure 1-4 Swivel schemes for 4 and 6 pairs of roller boxes

2. PROJECT DESCRIPTION

2.1 Problem definition

During a pipelay process, pipes and rollers get in contact directly. Since both the pipe and roller are cylindrical tubes, it is a point contact between them. Load on a single roller of *Solitaire* is about 15 metric tons in normal case. Large forces loading on a point result in a large local stress situation. There is coating on the roller in order to avoid damage to the pipe. The coating is made of polyurethane (PU). Since PU has a lower stiffness compared to steel, there will be a larger deformation on the PU coating. The deformation vanishes when the roller rotates forward. The same position of the coating will deform again when it meets the pipe. The periodic load causes a faster failure of the coating. When an 18" pipe moves on the roller with maximum design loads, the deformation of the coating is 11.4 mm [4] which indicates that the diameter of the point contact area is about 160 mm. The smaller the pipe is, the smaller contact area is and the larger the Von Mises stress of coating is.

Figure 2-1 Damage on rollers of *Solitaire*

In the normal situation, loads on rollers are distributed by the rotation of roller frames. However, hinge rotations are constrained to have enough stiffness to support the pipe. The drawback of constrains is that rollers cannot all contact the pipes. As shown in Figure 2-2, when a pipe pushes a secondary frame to rotate by angle β, but the secondary frame can only rotate by α which is smaller than β due to constrains, there is a gap between the pipe and rollers. Therefore, loading does not distribute uniformly when irregular structures move over the roller box. There is a high peak load on one of the rollers. The higher peak load accelerates failure of the coating.

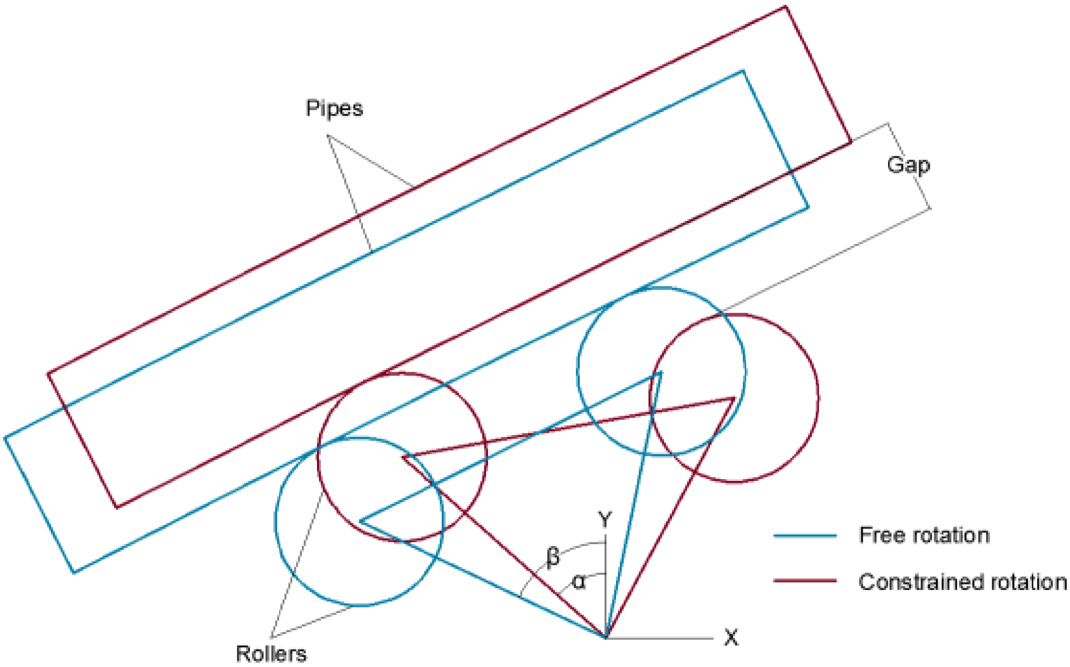

Figure 2-2 Explanation of constrained rotation

Once the coating fails, the roller has to undergo maintenance. The maintenance process is simply described as bellow:

- The vessel sails to shore
- Rollers are disassembled from the roller boxes
- Rollers are sent to manufacturer
- Old coatings are removed from the roller and new coatings are casted
- New rollers are sent back to the vessel and installed on the roller box

According to technical department and procurement department of Allseas, the cost includes steel disassembling and assembling, recoating and transporting. In addition, interval of production leads to a huger cost. If the life span of the coating is longer or the maintenance process is optimised, the cost can be saved.

This assignment is to propose concepts of a roller box on which the coating has a longer lifespan and decrease the maintenance cost. Discussion about feasibility of all concepts and a basic analysis about the selected concept will be performed too.

2.2 Approach

To perform the assignment systematically, the project is divided into four phases:

- In the research phase, the current roller box system is researched to gain an over view of the roller box that has to be designed.
- In the analysis phase, the problem of this assignment is specified. The objective and requirements of the previous phase are translated into criteria for the design.
- In the concept design phase, the functions of each components of roller box are determined. For each function several solutions are proposed and presented in a morphological box. Concept designs can be derived by combining solutions from the morphological box. A final concept is selected.
- In the concept design phase, the selected concept is more specified.

Boundaries of this project

The boundary conditions of this project are as follows:

- The main interest of this project is to generate a concept design of a roller box which decreases contact stress between pipes and coating. The connections between parts are excluded from this project because of time limitation of the internship.
- The project is performed on the roller box system of *Solitaire*. Because *Solitaire* has the largest load among the vessels which have already been involved in many projects, *Solitaire* suffers the problems described in section 2.1 typically.
- Only the behaviour of the double seesaw roller box will be studied. The other types of roller box, height adjustment system and support beam are excluded from this project. When needed, they will be modelled as simple models.
- Only the operational situation will be considered, which means there is a pipe on roller boxes.
- Only static analyses are performed. Dynamic analyses are excluded from this project.

3. CONCEPTS OF ROLLERBOX

3.1 Design requirements and specifications

This project aims to design a new roller box with a longer lifespan. To achieve this objective, the new design should be able to decrease the stress on the coating.

- The loads on the roller box can be applied uniformly along the roller box. In this way, high peak stress is less likely to happen at each contact area;
- New roller box can be designed with larger contact areas. Stress level is less at each contact area when the loads are the same.

In summary, a design of a roller box is according to following requirements:

Functionality:
- Support and guide the pipe in Y and Z directions;
- Self-adaptive to contact pipes;
- Support the pipe with enough load capacity
- Workable in the sea environment;
- Applicable for pipes with diameter from 8″ to 60″ OD;
- Height adjustable on stinger.

Maintenance:
- Easier maintenance
- Larger service intervals

Other requirements:
- Reduced stress level at the contact area between the pipe and roller box
- As light as possible

3.2 Concepts

3.2.1 General

The requirements determine the main functions of seesaw roller box components. Due to ship movements and environmental factors, pipelines have movements in Y and Z directions. Structures of roller box should constrain large movements of pipelines in the Y direction. Otherwise the pipeline will have severe dynamic movements in the water. This increases risk of structure failure of pipelines in the water and dramatic dynamic behaviour of the ship.

The roller boxes should not damage the surface of the pipelines. Since the curvature of pipelines changes during pipe lay, the roller boxes should be self-adaptive to contact pipelines. The structure of the roller boxes should be strong enough to transfer loads from the pipelines and work in the sea environment. Solutions are better viewed in Figure 3-1. A morphologic box shown in Figure 3-2 is a tool to generate concepts.

- A1: Rollers are the same as the existing rollers.
- A2: PU track is made of PU and rotate around two roller cores.
- A3: Steel track 1 is made of track plates and rotates over two roller cores. Each steel plate has PU coating bonded to the surface. Two track plates can be connected with pins or bars.
- A4: Steel track 2 is made of track plates which are connected to 2 wheels at the end of each steel plate. A track plate is shown in Figure 3-3. Each steel plate has PU coating bonded to the surface.

- B1: Normal frame is the same as the existing secondary frame
- B2: No secondary frame
- B3: Frame with rails is a V-shape frame with rails around it.

- C1: Normal frame is the same as the existing main frame
- C2: Flat frame is similar as the existing main frame but with flexible supports
- C3: V-shape frame is in V-shape with flexible supports

Concept 1(A2-B1-C1):

Figure 3-1 Solutions

Figure 3-2 Morphologic box

3.2.1 Explanation of the concepts

Concepts are generated by combining solutions of each component. There are mainly 7 concepts:

Concept 1(A2-B1-C1):

A PU track and two roller cores are installed on the a normal secondary frame, the main frame is normal frame.

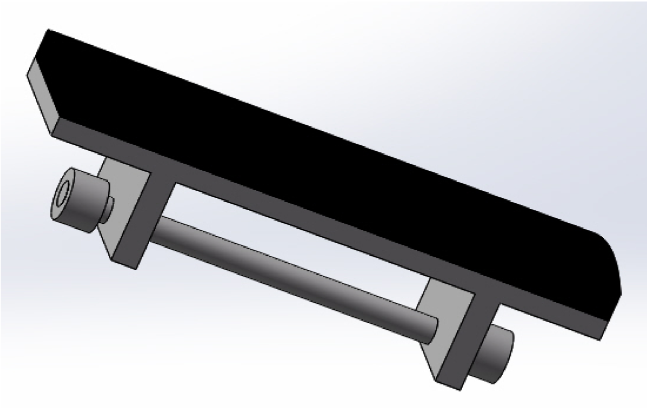

Figure 3-3 Track plate of steel track 2

The PU track is connected to the roller cores directly and rotates around roller cores when pipes move forwards. Secondary frames rotate via sub hinges and main frame rotates via main hinges.

The coating is glued on the current rollers and it is not easy to be removed or get new coating locally. Since steel structures are heavy and a large amount of manpower and material resources are needed to get components disassembled, rollers have to be returned to factories to repair. The PU track rotates on roller cores and can be disassembled as a single piece. Without disassembling steel parts, it is lighter and easier for human to get it replaced locally when there is damage.

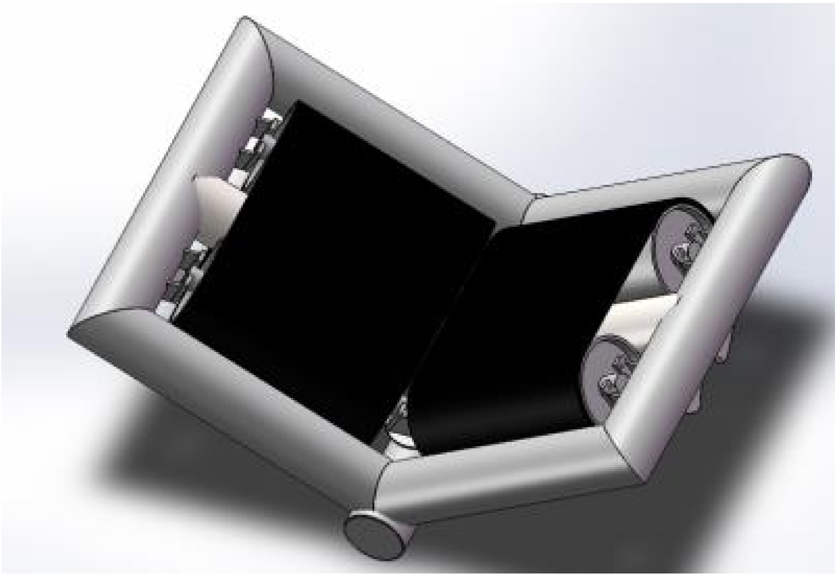

Figure 3-4 Secondary frame and PU track of concept 1

The secondary frame and main frame remain as the normal design. They work together via a seesaw mechanism to make the roller box self-adaptive to contact rollers.

Concept 2(A3-B1-C1):

A steel track 1 and two roller cores are installed on a normal secondary frame, the main frame is normal frame.

Steel track 1 consists of several track plates. Track plates are connected as a chain to make a closed track. Two track plates can be connected by pins. The track is installed on the roller cores and rotates around the roller cores when pipes move forwards. The secondary frames rotate via sub hinges and main frame rotates via the main hinge.

The contact between the pipe and rollers of the current design is point contact. The contact area becomes larger if there is a line contact, which helps to decrease stress level of the coating when loads remain the same. The side section view of the track plate is rectangular instead of the circular cross section of a roller. Therefore, contact between the PU coating on the track plate and pipe is regarded as a line contact.

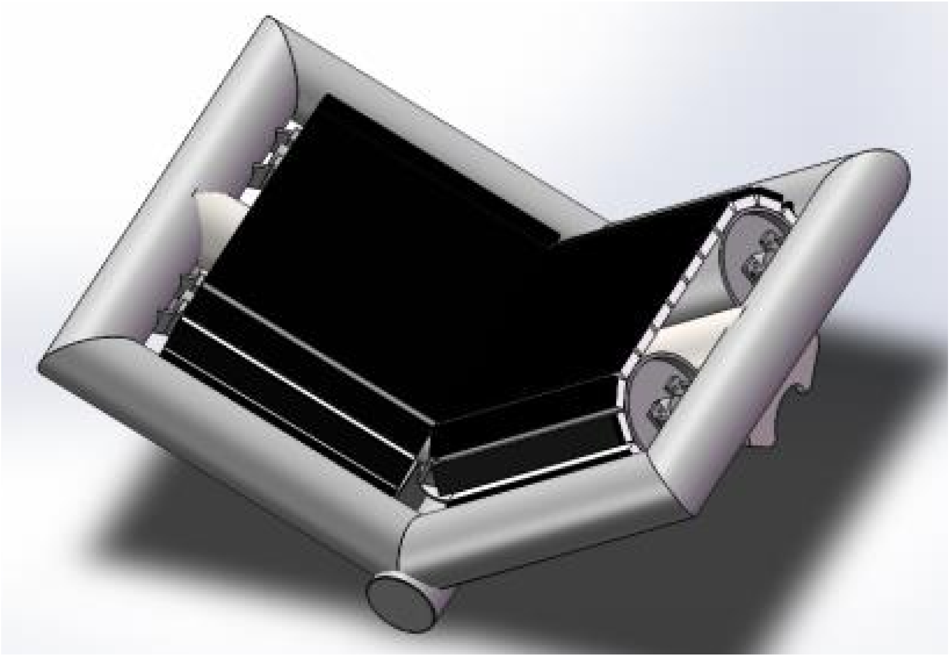
Figure 3-5 Secondary frame and steel track of concept 2

Concept 3(A4-B3-C1):

A steel track 2 is installed on a secondary frame with rails. The main frame is a normal frame.

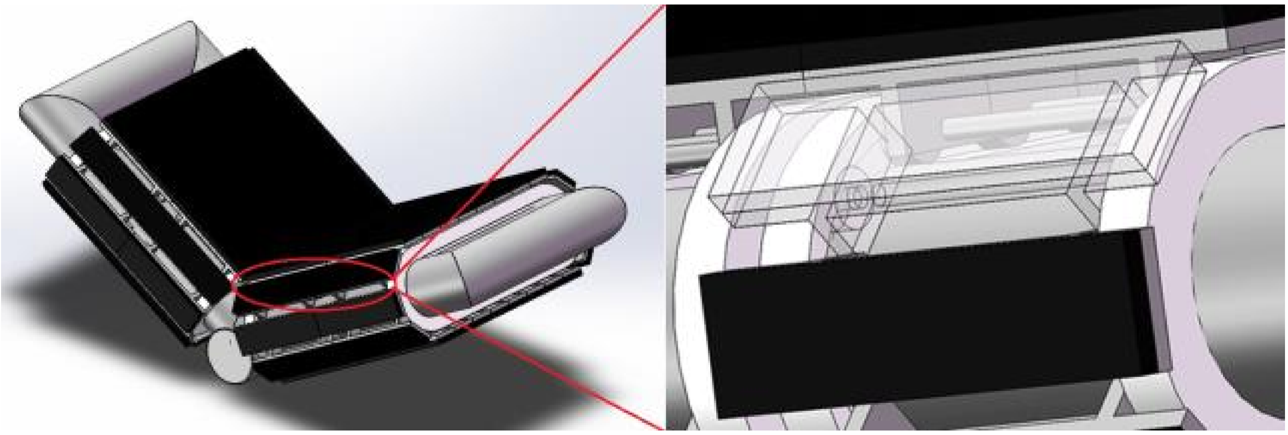
Figure 3-6 Steel track 2 and secondary frame of Concept 3

The secondary frame rotates via sub hinges and main frame rotates on the main hinge. There are two support points on the current secondary frame, namely where the rollers locate. The rails in this concept are made of steel and should be stiff enough to distribute the pipe loads along the rail. The loads on each track plate are less. Therefore, the stress level on the coating is much less. The track plate design is the same as concept 2.

Steel track 2 consists of several track plates which are connected as a chain to make a closed track. Only the track plates on the top of the track contact the pipeline directly. As mentioned in section 2.1, the diameter of point contact area is about 160 mm. The width of the track plate is 160 mm in this concept. In order to compare with the current design, the length and height of the track are similar to the dimensions of the secondary frame which is shown in Table 1.2. In this concept, there are 7 track plates on the top of the track, which is a conservative design. One track plate provides one contact point with the pipeline. With more contact points, the load can be divided in smaller values and the stress will be less.

There are rails on the secondary frame. The track moves on the rails via the wheels. The wheels are supported by the rails and constrained to move in longitudinal direction only. The track plate and wheels are connected by a pin or a shaft. The wheels can be bearings which should suffer axial and radial loads simultaneously. The limitation of space for the wheels and rails should be checked.

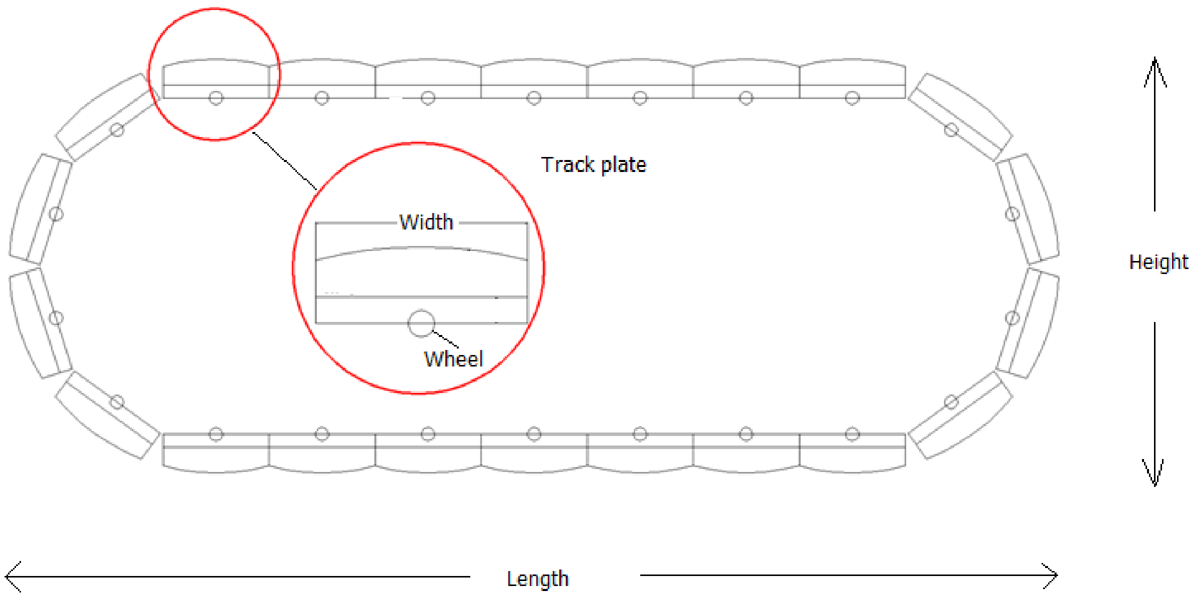

Figure 3-7 Rough layout of a steel track 2

Concept 4(A1-B2-C2):

Several rollers are installed on a flat main frame with flexible supports and there is no secondary frame.

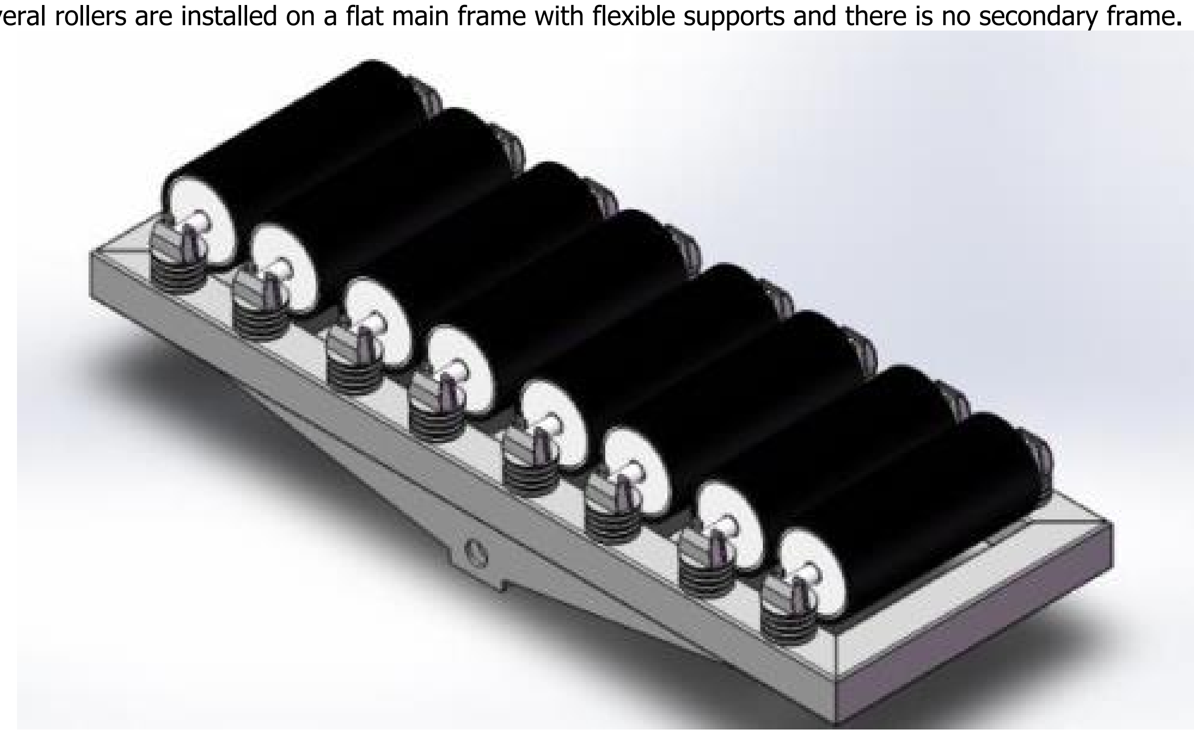

Figure 3-8 Concept 4

This concept does not have a secondary frame. The flat main frame is equipped with flexible supports with relatively small stiffness. Due to the flexibility of the supports, the rollers are able to move up and down in vertical direction when loads are changing when pipes move forwards. Disc springs are used as the flexible supports which should be constrained in the horizontal and longitudinal directions. Figure 3-9 shows how the springs can be fixed in the horizontal and longitudinal directions. The bars are fixed and the spring is fixed to the support plate. The support plate can slide on the bars freely in Z direction but it is constrained movement in the X and Y direction. The rollers are installed on the supports directly. The main frame rotates on the main hinge.

The loads on the roller box keep changing when the pipeline moves forwards. Concept 1, 2, 3 use the seesaw mechanism to achieve self-adaption to contact pipelines. Another mechanism to implement self-adaption is using flexible system. The flexible system can deform to avoid high load peak when loads change suddenly. In this concept, spring supports are installed on the main frame and the support rollers directly. A secondary frame is not necessary in this concept. Rollers can move up and down to follow the movement of pipelines.

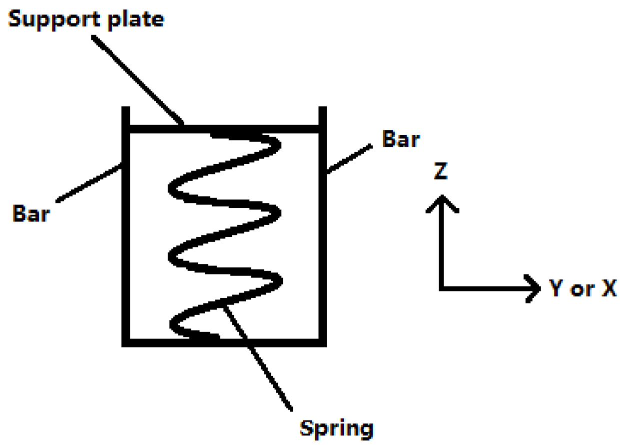

Figure 3-9 Explanation of constrains of springs

Concept 5(A1-B2-C3):

Several rollers are installed on V-shape a main frame with flexible supports and there is no secondary frame.

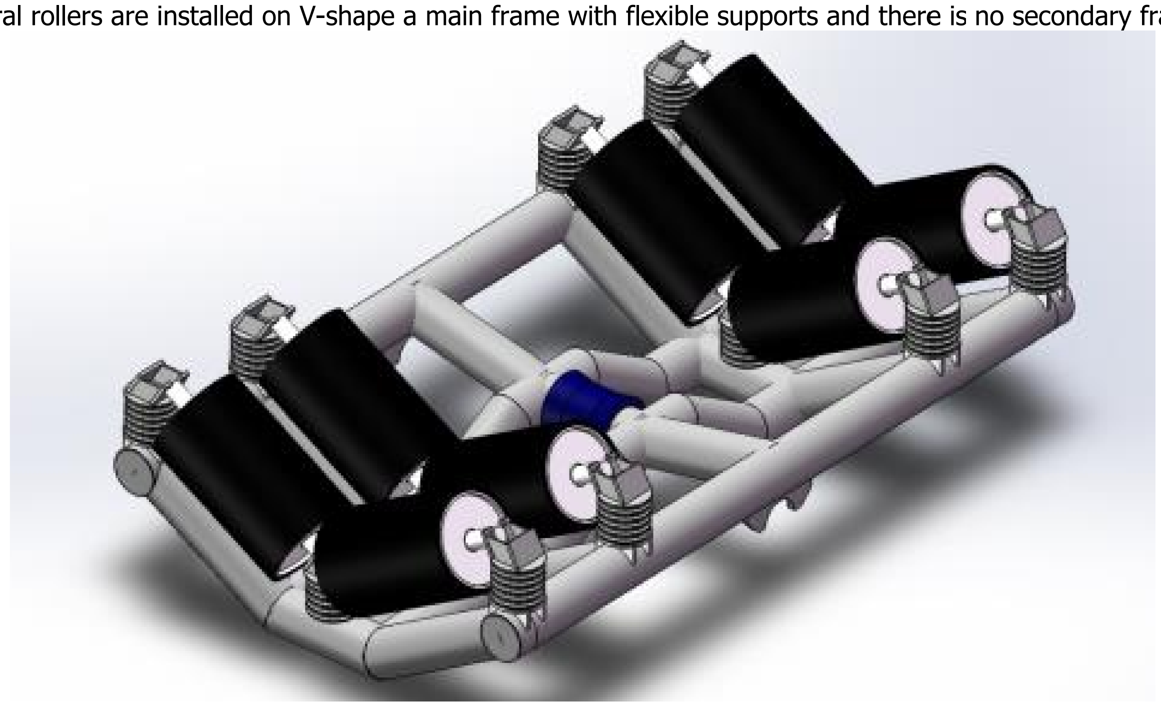

Figure 3-10 Concept 5

This concept doesn't have a secondary frame. The V-shaped main frame is installed with flexible supports that have a relatively small stiffness. Due to the flexibility of supports, the rollers are able to move up and down when loads are changing. The flexible supports are constrained in the horizontal and vertical direction. The rollers are installed on the supports directly. The main frame rotates on the main hinge.

This concept is similar with concept 4. While concept 4 only supports pipelines in vertical direction, the main frame in this concept is designed as a V-shape frame in order to support the pipe in the horizontal direction as well.

Concept 6(A3-B2-C3):

A steel track 1 and two roller cores are installed in a V-shaped main frame with flexible supports and there is no secondary frame.

The V-shape main frame is installed with flexible supports that have a relatively small stiffness. Due to the flexibility of supports, the roller cores are able to move up and down when loads are changing. The flexible supports should be constrained in the horizontal and vertical direction. The track is connected to roller cores which are installed on the supports. The main frame rotates on the main hinge.

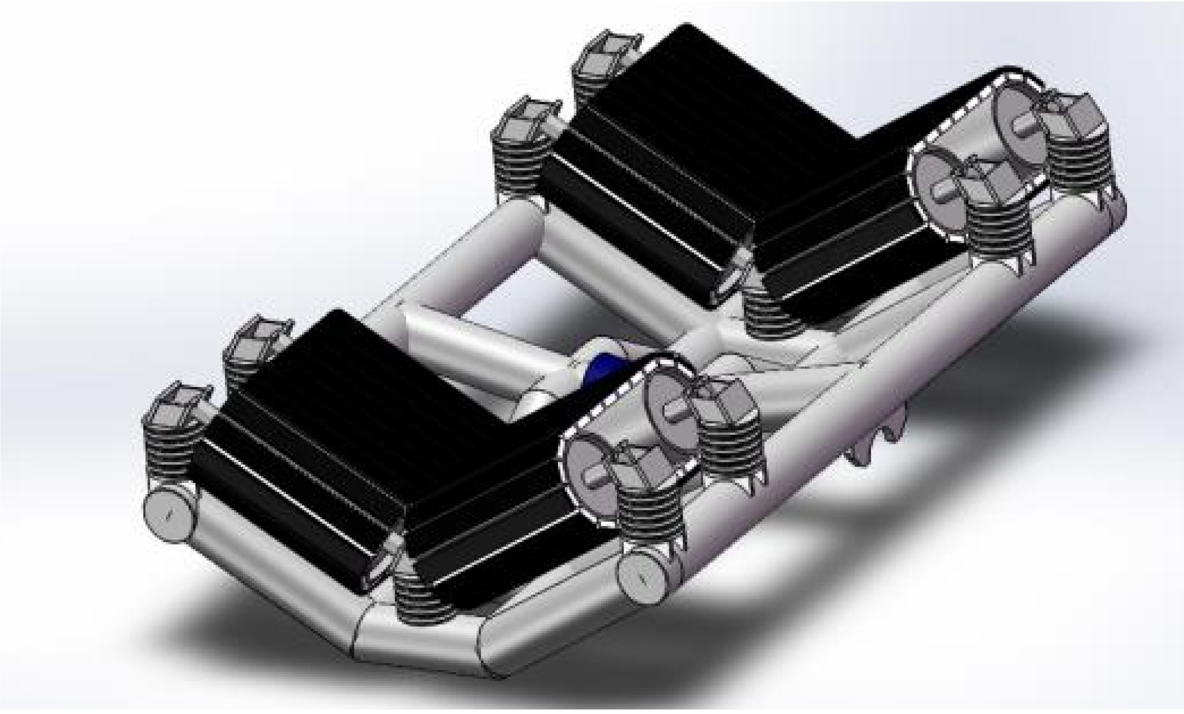

Figure 3-11 Concept 6

Concept 7(A4-B3-C3):

Steel track 2 and a modified secondary frame with rails are installed on V-shape main frame with flexible supports.

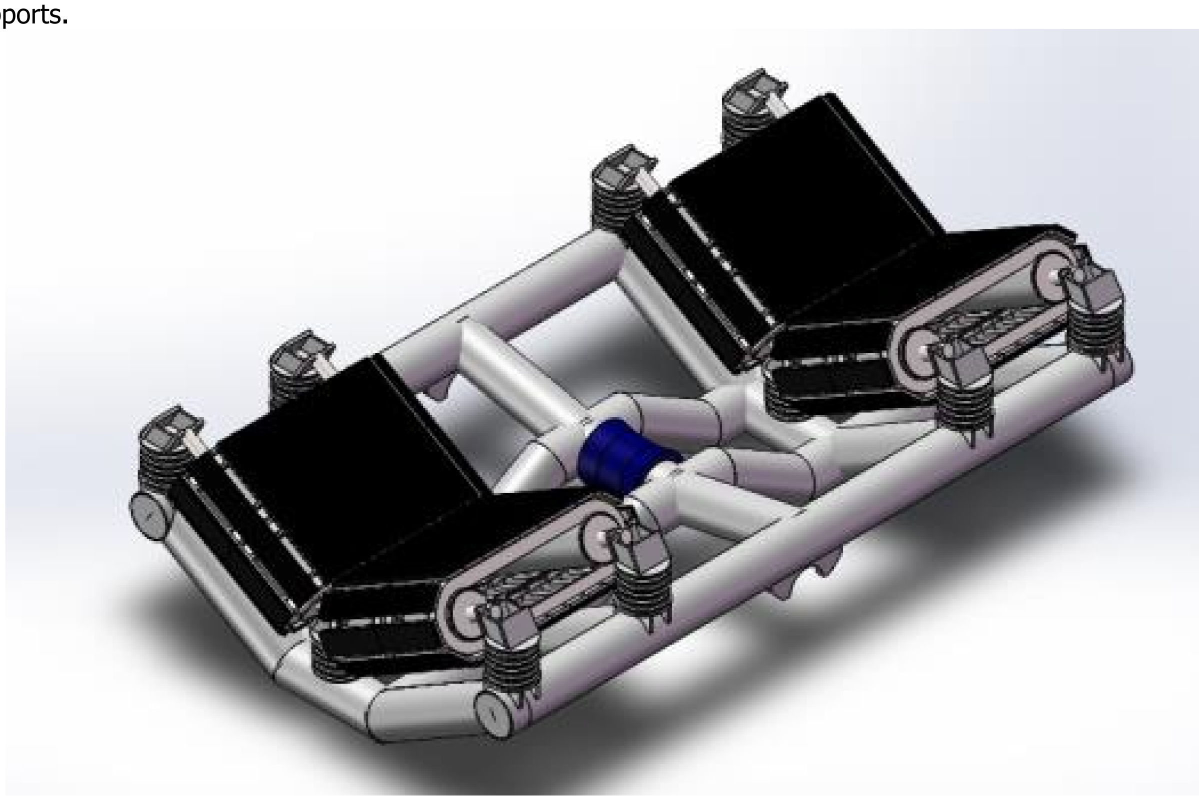

Figure 3-12 Concept 7

The modified secondary frame is shown in Figure 3-14. If it is not modified, the rotation around the Y axis will be constrained since there are more constrains in the X direction. This concept combines concept 3 and concept 5. Loads are distributed uniformly on rails and there are no high peak loads because of the flexible system.

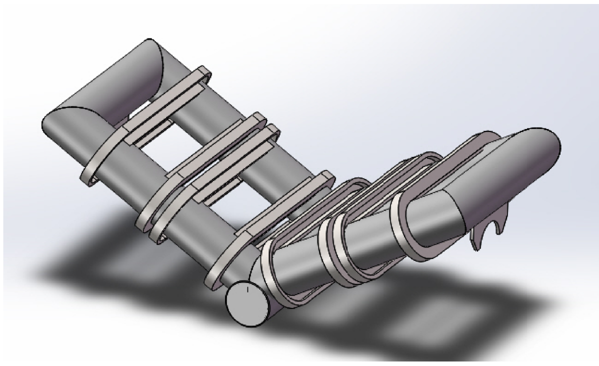

Figure 3-13 Secondary frame with rails

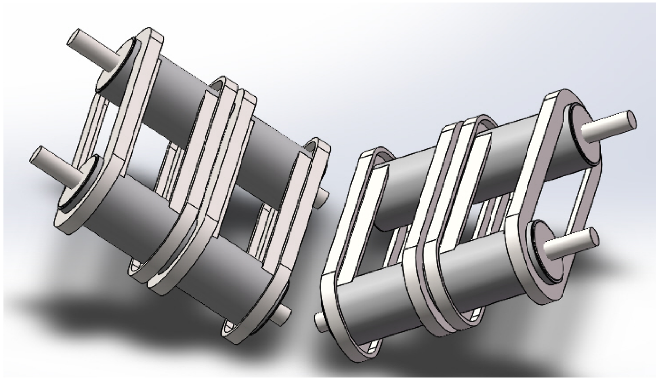

Figure 3-14 Modified secondary frame with rails

3.3 Concept choice

In this section, further research of each concept will be performed and the choice of the concept will be explained.

Concept 1

Concept 1 is able to support pipelines in vertical and horizontal directions. The secondary frame and main frame work together to adapt to the curvature of the pipelines. Maintenance is easier. Weight does not change very much compared to the current design.

It can be a V-belt connection between the PU track and the roller cores. The gap between the PU track and roller cores causes more relative movements between the coating and roller cores. Compared to coating on the current design, the load condition on the surface of coating does not change and there is more friction.

Concept 2

Concept 2 can support pipelines in vertical and horizontal directions. The secondary frame and main frame work together to adapt to the curvature of the pipelines. A piece of track plate can be replaced locally when the coating fails. Without disassembling other steel parts, the maintenance becomes easier. However, there are more components. This increases the chance of structure failure. With higher frequencies of maintenance, the service interval gets smaller, which is not economic.

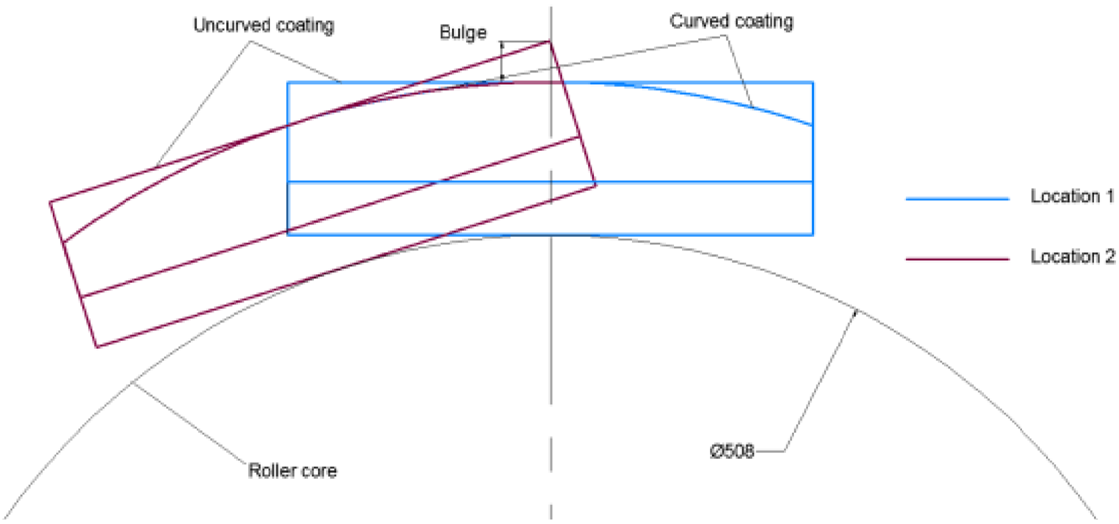

Figure 3-15 Explanation of curved top surface of coating

As shown in Figure 3-13, the bulge part will make the pipeline move up and down. In order to keep the pipe move smoothly, the side section view of the coating should not be rectangular. The surface of the coating is curved.

The stress level of the coating on the track plate is checked by ANSYS. The loads are determined by design local roller box loads [2] which are shown in Table 3.1.

	Fy (kN)	Fz (kN)
Value	240	-1200

Table 3.1 Design local roller box loads

There are 8 support points. Vertical force Fz is loaded on each roller equally. The horizontal force Fy is loaded on 4 support points at one side of the track equally. Loads in this analysis are listed below.

Table 3.2 Loads on the a support point

	Fy(kN)	Fz(kN)
Value	60	-150

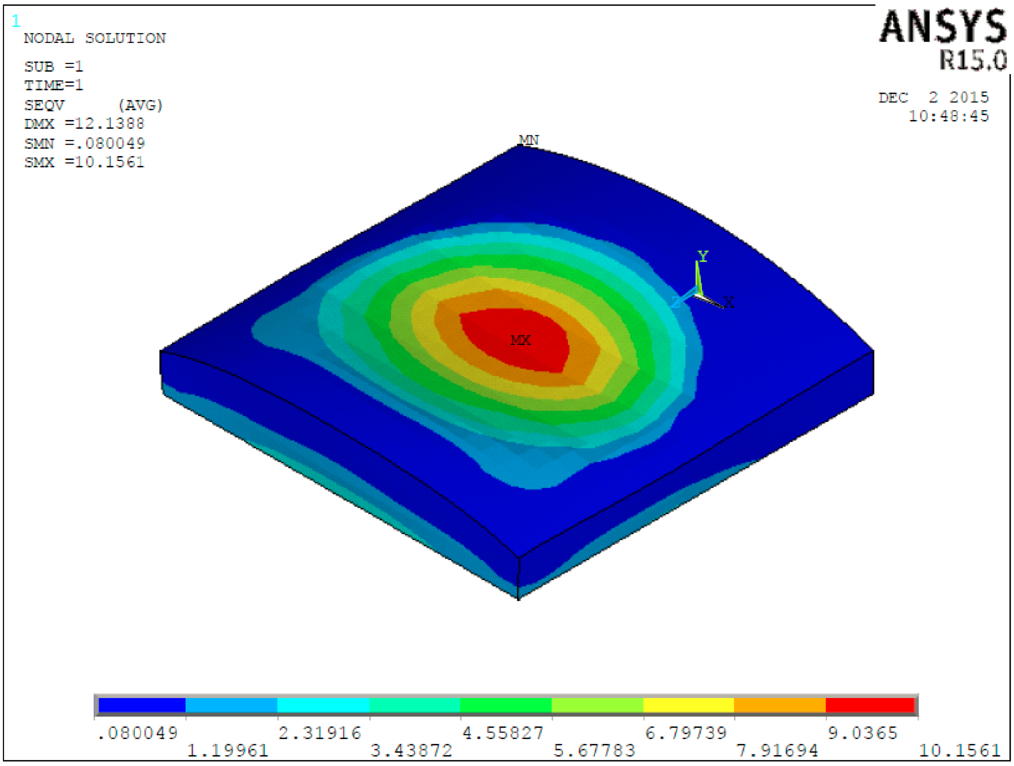

Figure 3-16 Von Mises stress of track plate coating

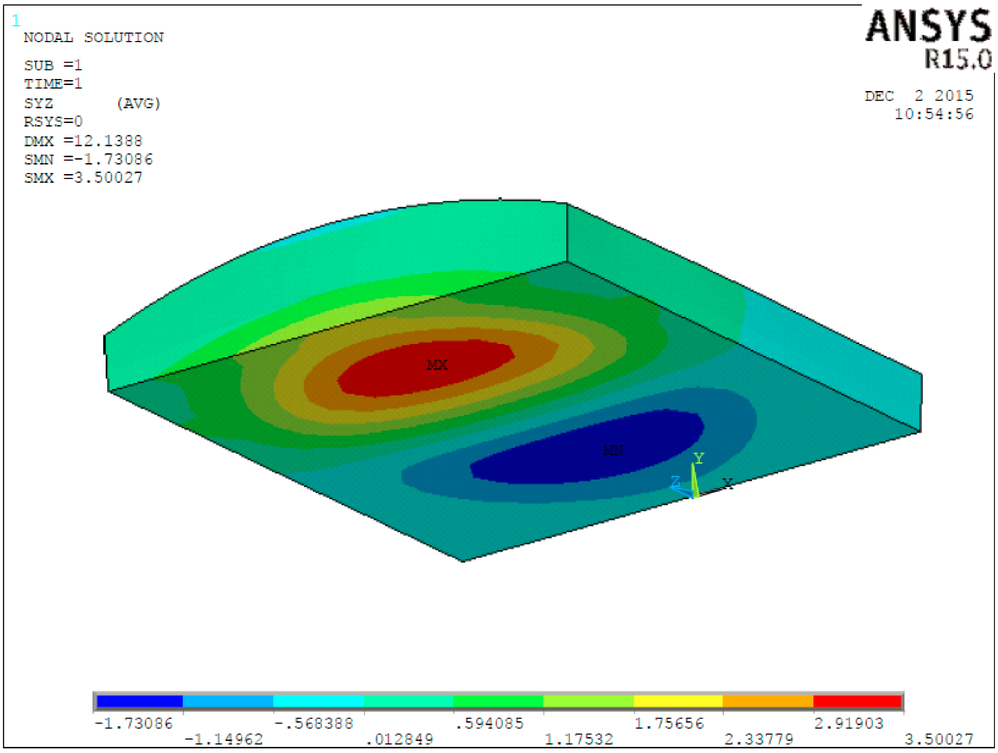

Figure 3-17 Shear stress of track plate coating

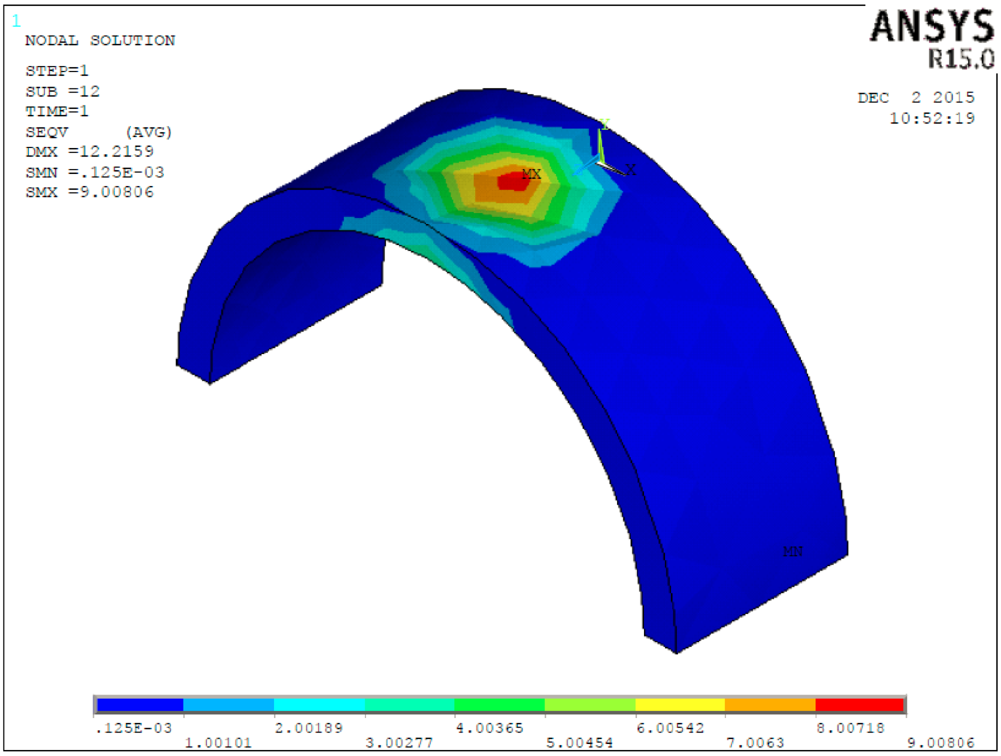

Figure 3-18 Von Mises stress of roller coating

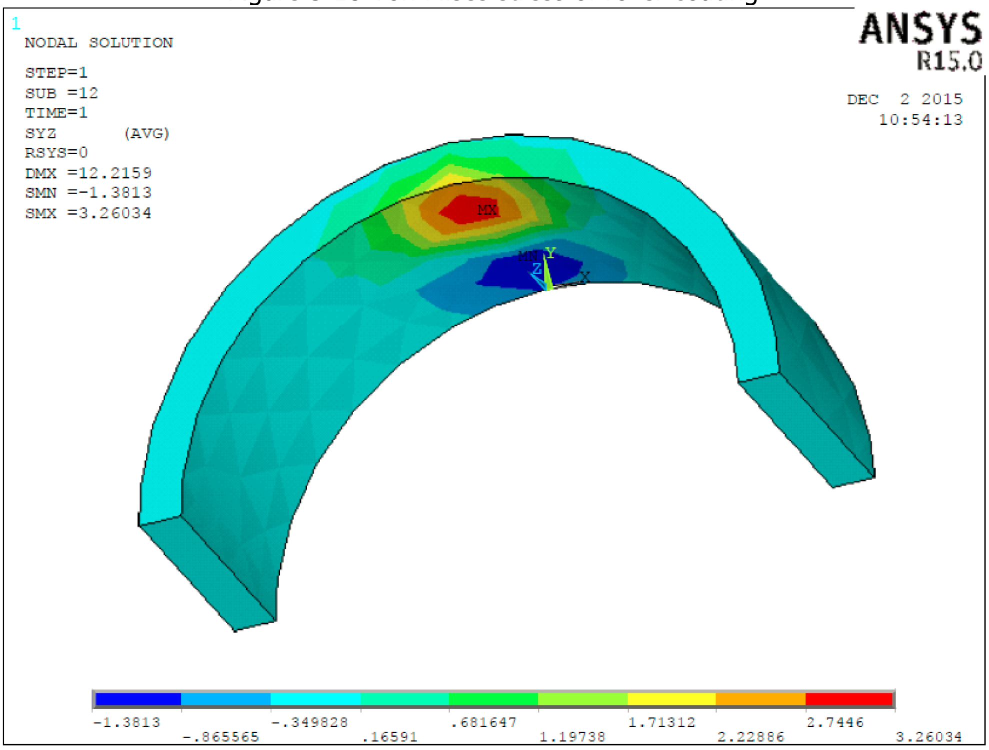

Figure 3-19 Shear stress of roller coating

Table 3.3 Simulation results of maximum values of stresses

	Von Mises stress	Shear stress in YZ plane (Coordinate system of ANSYS)
	[MPa]	[MPa]
Coating of steel track 1	10.15	3.50
Coating of rollers	9.01	3.26

The simulation results of stresses are shown in Figure 3-16 to Figure 3-19. Table 3.3 shows that the stress level of coating on track plate is almost the same as that of coating on roller cores. This means the track plates do not contribute very much to decrease stress level of coatings.

Table 3.4 Loads on the a support point

	Fy(kN)	Fz(kN)
Value	120	-300

If the rotation of the secondary frame is constrained as shown in Figure 2-2, the load applied on a single roller is shown in Table 3.4. The stress level on the coatings will be higher than simulation results in Table 3.3.

The current roller core has 508mm diameter which is determined by the load capacity of coating [4]. The load capacity of the coating on the track plate is not sensitive to the diameter of the roller cores. The coating bottom surface is bonded to a track plate, which means the coating is fixed on a flat steel plate. If the track plate is stiff enough, loads and constraints of the coating do not change. Therefore the diameter of roller cores does not affect the coating. Roller cores can be replaced by smaller diameter ones. But the roller cores cannot be too small. Because there should be enough space for the track to rotate and the load capacity of the roller cores should be enough to support the pipelines. If the steel tracks are installed on roller cores with a diameter of 323.9 mm, total weight of a roller box will increase because track plates add more weight. Weight estimation and ANSYS analysis settings are available in Appendix B

Concept 3

Concept 3 is able to support pipelines in vertical and horizontal directions. The secondary frame and main frame work together to adapt to the curvature of pipelines. A track plate can be replaced locally when the coating fails. Without disassembling other steel parts, the maintenance becomes easier. However, there are more components. This increases the chance of structure failure. With higher frequencies of maintenance, the service interval gets smaller, which is not economic.

The secondary frames are made of circular tubes and there is no roller in this concept. Therefore the weight of this concept is lighter compared to the current design.

Stress level of coating on the track plate is checked by ANSYS. The loads are determined by design local roller box loads [2] which are shown in Table 3.1. There are 4 tracks on a single roller box. Vertical force Fz is loaded on each track equally. Horizontal force Fy is loaded on 2 tracks at one side of the track equally.

There are two load cases in this analysis. In case 1, the force on a single track is distributed uniformly along 7 track plates which contact the pipelines directly. In case 2, loads are the same in Table 3.4. Because the rotation of the secondary frame is constrained as shown in Figure 2-2, only one track plate supports the pipeline.

Table 3.5 Loads on the a support point

	Fy(kN)	Fz(kN)
Value	8.6	-21.5

The simulation results are shown in Figure 3-20 and Figure 3-21. Table 3.6 shows that the stress level of coating is significantly less than that of rollers. The rates of stress change between the coating of rollers and the coating of steel track 2 are shown in Table 3.6. ANSYS analysis inputs are available in Appendix C.

Table 3.6 Simulation results of maximum values of stresses

	Von Mises stress	Shear stress in YZ plane (Coordinate system of ANSYS)
	[MPa]	[MPa]
Coating of rollers	9.01	3.26
Coating of steel track 2	3.29	1.03
Relative change rate	68%	63%

Concept 4

Concept 4 is able to support pipelines in vertical direction but not able to support pipelines in horizontal direction. The maintenance procedure remains similar to the current design. There is no secondary frame, therefore total weight will be less. When an irregular structure moves forward, the force condition of the flexible system is shown below.

Relationships of forces, spring deformations are given below:

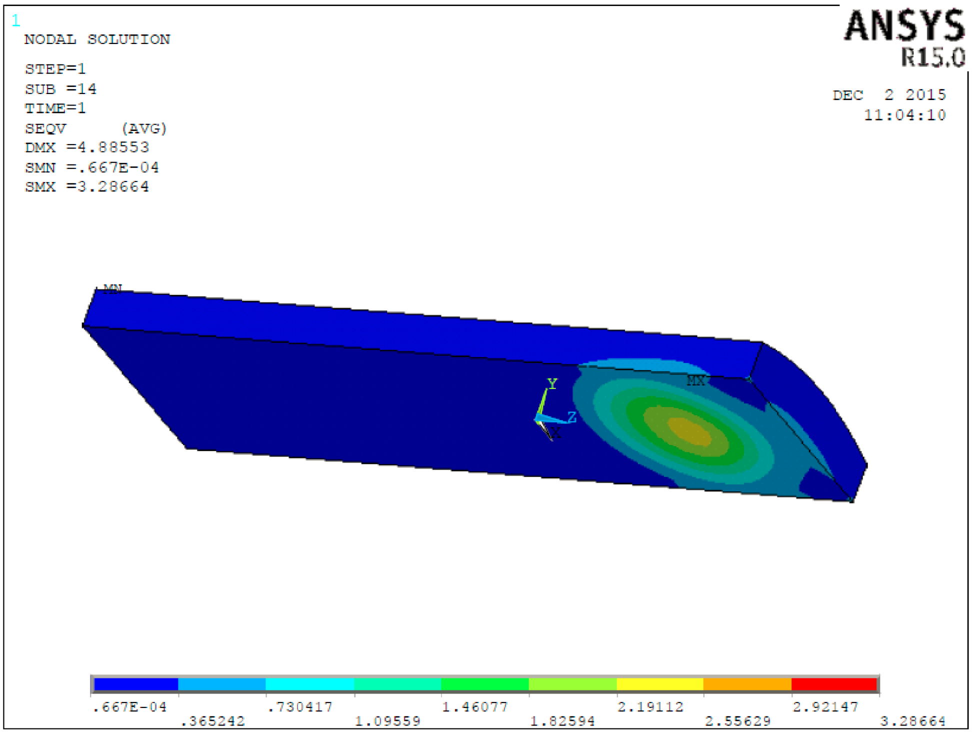

Figure 3-20 Von Mises stress

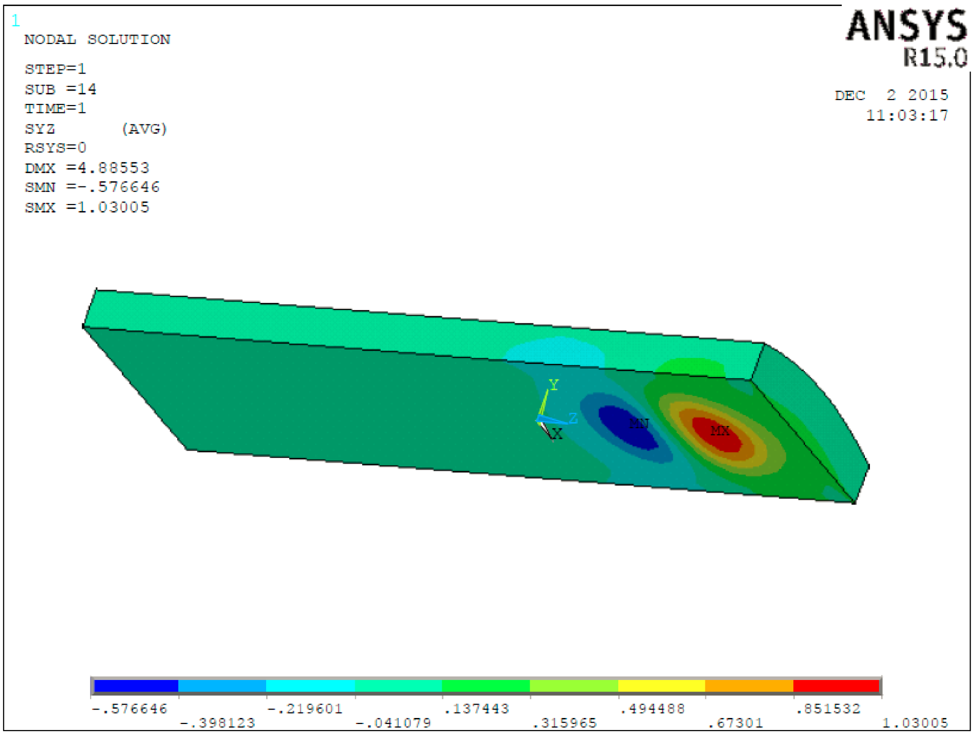

Figure 3-21 shear stress

Knowns:

$\Delta x, F_C, F_0$
$F_0 = kx_0$
$F_1 = kx_1$
$F_2 = kx_2$
$2F_0 = F_1 + F_2$
$\Delta x_1 = x_0 - x_1$

$\Delta x_2 = x_2 - x_0$
$\Delta F = F_2 - F_1 = k\Delta x$

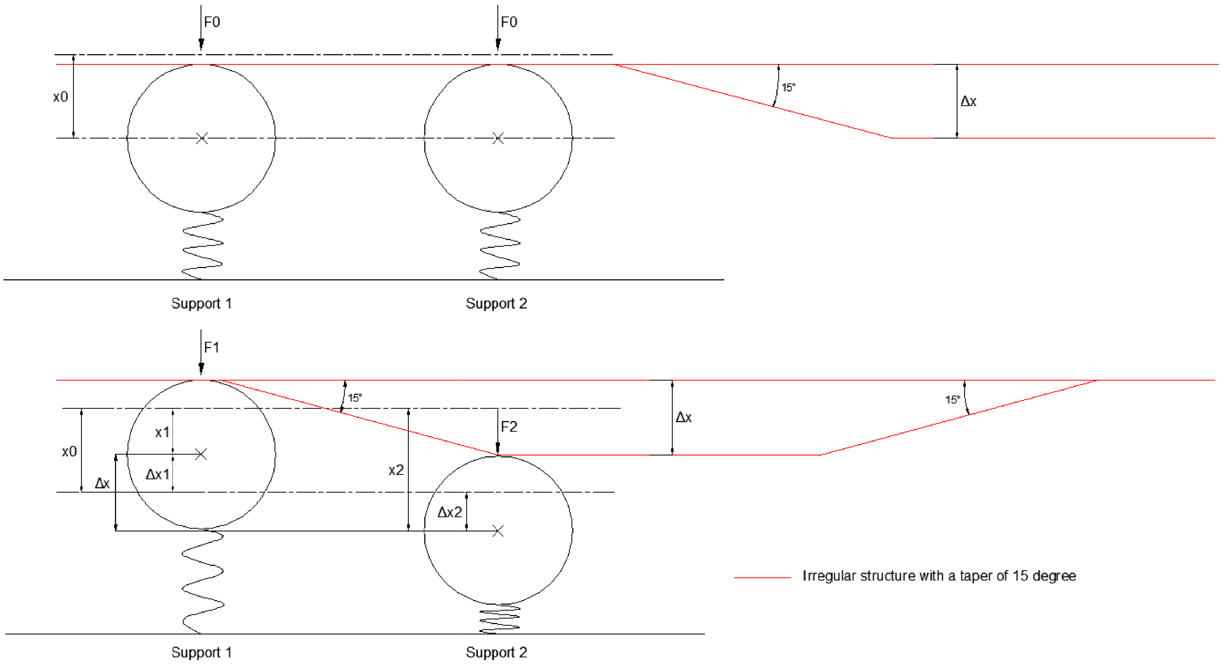

Figure 3-22 Two supports spring system

F_0 - load on the support when loads are distributed on all supports uniformly
F_1 - load on the support 1
F_2 - load on the support 2
F_C - design load capacity of one single support
ΔF - allowable load change between two supports
x_0 - initial spring deformation, with load uniformly on each spring.
x_1 - spring deformation at the support 1
x_2 - spring deformation at the support 2
Δx - spring deformation difference between two supports
Δx_1 - spring deformation difference of spring 1
Δx_2 - spring deformation difference of spring 2

The geometry of the irregular structure determines the maximum deformation difference between the neighbour springs. The allowable load change is determined by the difference between F_0 and F_C. The maximum stiffness which guarantees that the load would never exceed the design load capacity can be found.

Unknowns:

$$x_0 = \frac{x_1 + x_2}{2}$$

$$\Delta x_1 = x_0 - x_1 = \frac{x_1 + x_2}{2} - x_1 = \frac{x_2 - x_1}{2} = \frac{\Delta x}{2}$$

$$\Delta x_2 = x_2 - x_0 = x_2 - \frac{x_1 + x_2}{2} = \frac{x_2 - x_1}{2} = \frac{\Delta x}{2}$$

$$F_1 = F_0 - k \times \Delta x_1 = F_0 - \frac{k \times \Delta x}{2} = F_0 - \frac{\Delta F}{2}$$

$$F_2 = F_0 + k \times \Delta x_1 = F_0 + \frac{k \times \Delta x}{2} = F_0 + \frac{\Delta F}{2} \leq F_C$$

$$\Delta F \leq 2 \times (F_C - F_0)$$

$$k = \frac{\Delta F}{\Delta x}$$

$$x_0 = \frac{F_0}{k}$$

$$x_1 = \frac{F_1}{k}$$

$$x_2 = \frac{F_2}{k}$$

An example is available.

Example:
According to the design global roller box loads [2], the load on Roller Box 9 in case 1.10 is 800 kN. The load on each roller becomes 100 kN. When an inline structure moves over the roller boxes, diameter changes by 24″ and the radius changes by $\triangle$x=12″=304 mm. The load capacity of rollers whose roller core has a diameter of 508 mm is 150 kN [4].

Knows:

$$\Delta x = 304\ mm, F_C = 150kN, F_0 = 100\ kN$$

Unknowns:

$$\Delta F \leq 2 \times (F_C - F_0) = 2 \times (150kN - 100kN) = 100\ kN$$

$$k = \frac{\Delta F}{\Delta x} = 329\ N/mm$$

$$x_0 = \frac{F_0}{k} = 304\ mm$$

$$F_1 = F_0 - k \times \Delta x_1 = F_0 - \frac{k \times \Delta x}{2} = F_0 - \frac{\Delta F}{2} = 50\ kN$$

$$F_2 = 150\ kN$$

$$x_1 = \frac{F_1}{k} = 152\ mm$$

$$x_2 = \frac{F_2}{k} = 456\ mm$$

The deformations of springs can be found, which guides to choose a spring. When the stiffness is small enough, the load on each roller is controlled and less than the design load capacity. Since the disc springs can deform when the load changes, no loads drop on the tracks suddenly. Therefore there are no peak loads on a roller.

Concept 5

Concept 5 is similar to concept 4. But concept 5 is able to support pipelines in both vertical and horizontal directions.

Concept 6

Concept 6 can support pipelines in vertical and horizontal directions. Maintenance is easier but it has higher chance of structure failure because there are more components compared to the current design. There is no secondary frame. Therefore total weight will be less. Load condition is similar to concept 4. Since the disc springs can deform when the load changes, no loads drop on the tracks suddenly. Therefore there are no peak loads on a track. However, the steel track 1 does not decrease stress level of coating.

Concept 7

Concept 7 can support pipelines in vertical and horizontal directions. The modified secondary frame has four small rollers. Compared to the current design, the weight of the normal secondary frame has been removed in this concept. Therefore the total weight will be less. The maintenance gets easier but the track has a higher frequency of failure because of more components compared to the current design.

Similar to concept 4, since the disc springs can deform when the load changes, no loads drop on the tracks suddenly. Therefore there are no peak loads on a track. Because of the flexible system, steel track 2 can rotate to contact pipelines all the time, case 2 in concept 3 is not suitable for concept 7 anymore. Only case 1 of concept 3 is suitable in this concept, the stress level of coating decreases a lot compared to the current design.

According to the requirements and limitations, a concept choice table is made based on Table 3.1. A weigh factor is given to each criterion. The higher the weight factor is, the more important the criterion is. A higher mark indicates a better concept.

Table 3.1 Concept choice table

	Weigh factor	C1	C2	C3	C4	C5	C6	C7
Functionality	0.3	100	100	100	50	100	100	100
Load capacity	0.3	80	100	100	100	100	100	100
Stress level on coating	0.2	80	80	80	80	80	80	100
Weight	0.1	80	50	80	100	100	80	100
Maintenance	0.1	100	100	80	80	80	100	80
mark	1	88	91	92	79	94	94	98

According to Table 3.1, concept 7 is the best choice.

4. CONCEPT DESIGN

In this chapter the detailing of concept 7 is done. The next parts are taken into account:

- Type and main dimensions of main frame;
- Type and main dimensions of modified secondary frame with rails;
- Type and main dimensions of track plate;

The final version of the design is shown in Figure 4-1.

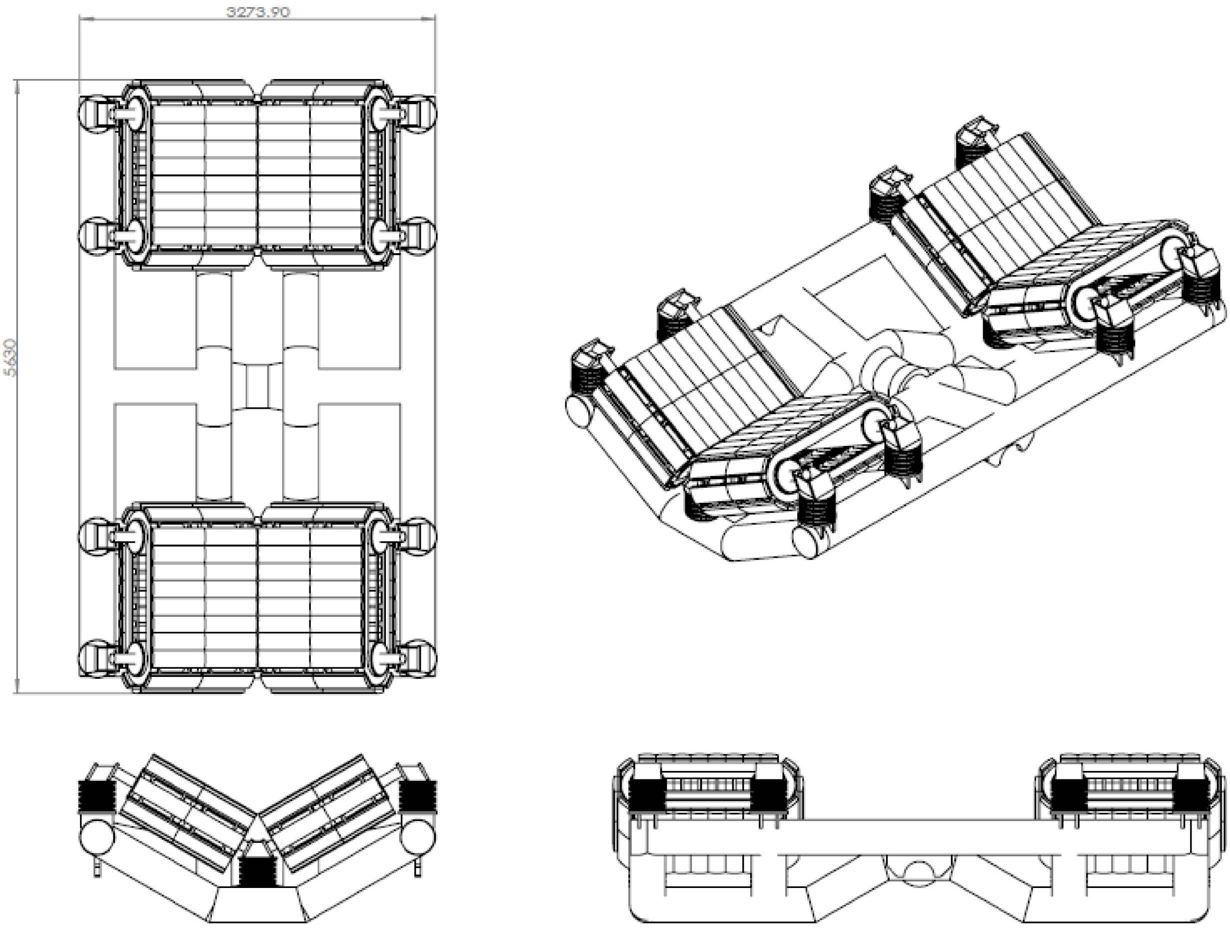

Figure 4-1 Concept 7

Main frame

Main frame is a V-shaped of 30° with the horizontal. It is made of steel. The distance between the centre line of the circular tubes are shown in Figure 4-2. Dimensions are determined based on the existing design. The length should be enough to hold the pipes between to roller boxes. The width should be enough to resist pipe movements in the horizontal direction.

Modified Secondary frame with rails

There are 4 frames with rails for a roller box, each has two rails. Therefore there are 8 tracks on a roller box. The ones closer to the centre of the roller box are called inner tracks. The other ones are called outside tracks. The inner tracks are easier to get damage since they support the pipelines more than the outside ones. If there is only one rail on each frame, the track plate will be replaced even the outside part is in good condition. Therefore only the inner track plate should be replaced if it is damaged. This helps to reduce cost. Besides, the track plate is lighter with a smaller width, which also makes maintenance easier.

This frame is also made of steel. Since the rail is an enclosed structure fixed on the frame, it should be able to support the track plates when they move both on the surface and the bottom of the frame. Dimensions are shown in Figure 4-3.

Track plate

Track plate consists of steel plate and coating. There are connection parts under the steel plate. The coating is made of Polyurethane and other parts are made of steel. The wheels should be able to move in the rails and strong enough to support the pipes. Drawing of steel track 2 is also available in Appendix D.

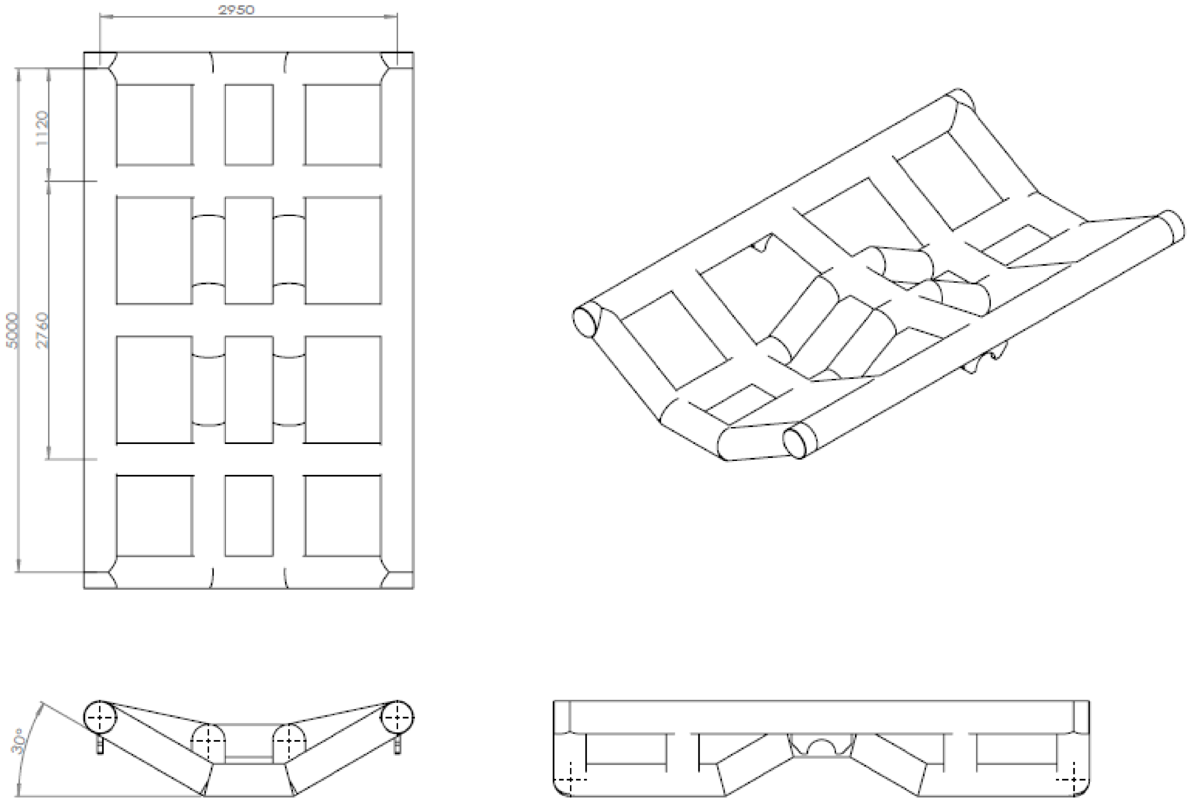

Figure 4-2 Main dimensions of main frame

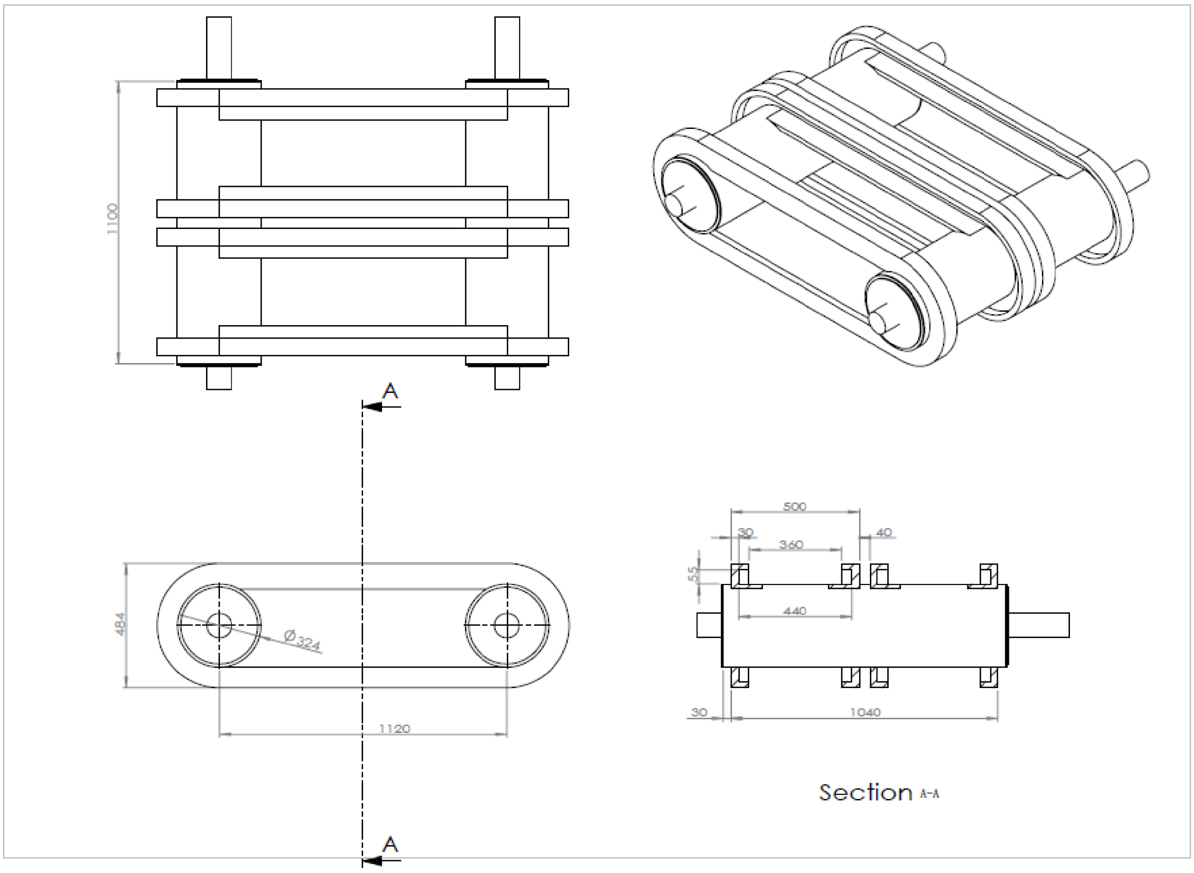

Figure 4-3 Frame with rails

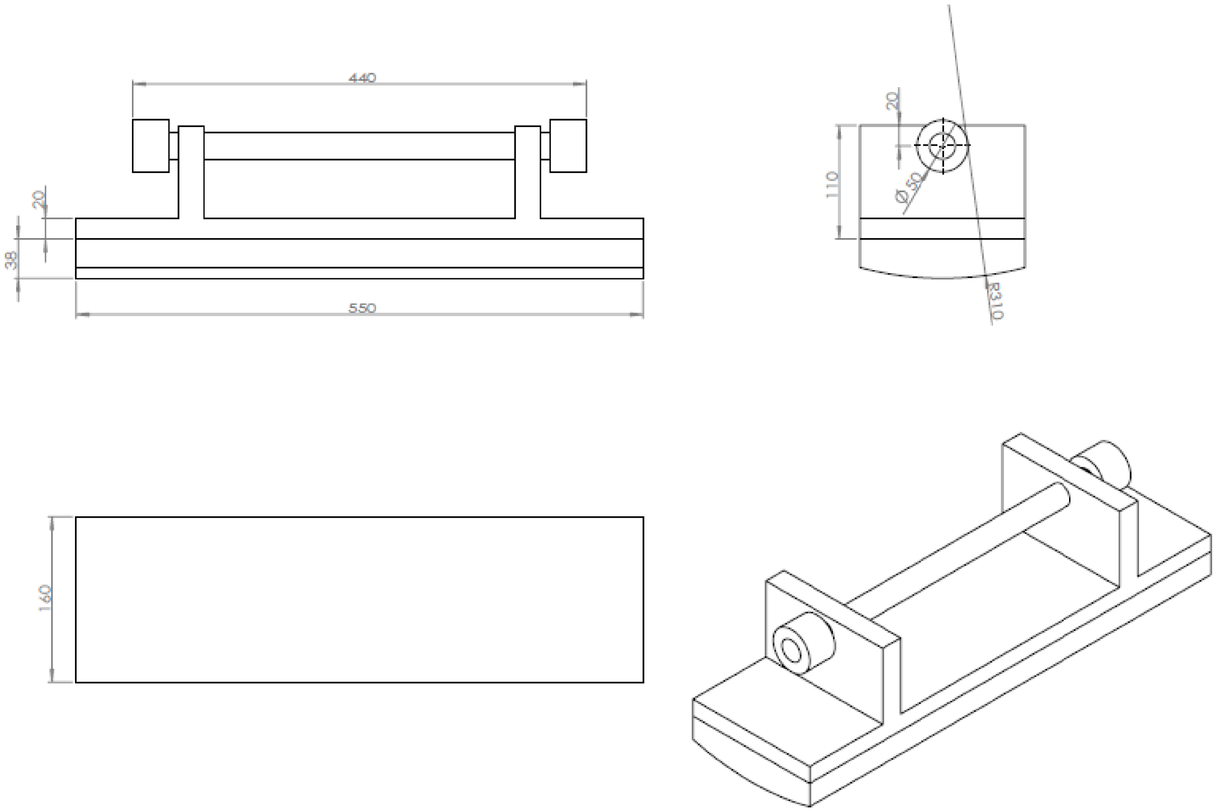

Figure 4-4 Track plate