Hydraulic Scissor Lift Project

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List of Symbols and Abbreviations

Symbols		*Constant values throughtout Report*
L	Length of Table	1000 mm
L_1	*Length from edge of table to* F_{A}	
l	*Length of leg*	850 mm
x	*Length between* W_{L} *and* F_{D}	
W_{T}	Weigth of Table	412 N
W_L	A*pplied Load*	5000 N
F_A	Reaction force at point A	
F_{D}	Reaction force at point D	
F_{CX}	Reaction force at point C in x axis	
F_{NX}	Piston force at point N in x axis	
F_{NY}	Piston force at point N in y axis	
F_N	Piston Force	
F_B	Reaction force at point B	
F_{MX}	Piston force at point M in x axis	
F_{MY}	Piston force at point N in y axis	
α	Angle between horizontal axis and scissor leg AB	
θ	Angle between horizontal axis and piston	

M_B	Bending Moment
P	Shear Force
N	Normal Force
σ_N	Normal Stress
σ_B	Bending Stress
τ_S	Shear Stress

<u>Abbreviations</u>

FBD	Free body diagram
SFD	Shear force diagram
BMD	Bending Moment diagram
NFD	Normal force diagram

1 FBDs

1.1 Introduction

This project describes the design calculation of a Hydralic Scissor Lift. Usually, a scissor lift is used to lift a certain object to a certain height example- for lifting a car to change a tire. A scisoor lift can be pnematic, mechanical or hydraulic.

In the following chapter first forces are determined at the scissor legs. After which stress and strain analysis is performed. Last part of this project will be weld analysis done at clevis of the hydralic piston.

1.2 Boundary Conditions

A basic model of the scissor lift is made in SolidWorks by keeping in mind the following boundary conditions-

- Constant load of 5KN is acting at 25% and 75% of table length
- Weight of table is considered to be 41.2 kg (Material of S355J2G3 is considered)
- Weight of components other than table are neglected
- Foot print of the lift should not exceed 1000 x 500 mm
- A general design for hydralic piston is considered
- Maximum height the lift can go (h_max) = 750 mm
- Minimum height the lift can go (h_min) = 350 mm

1.3 Setup

Figure 1 : Setup

1.4 Reaction Forces on Table

1.4.1 Case 1 – at h_max, Load at 25% of of Table length

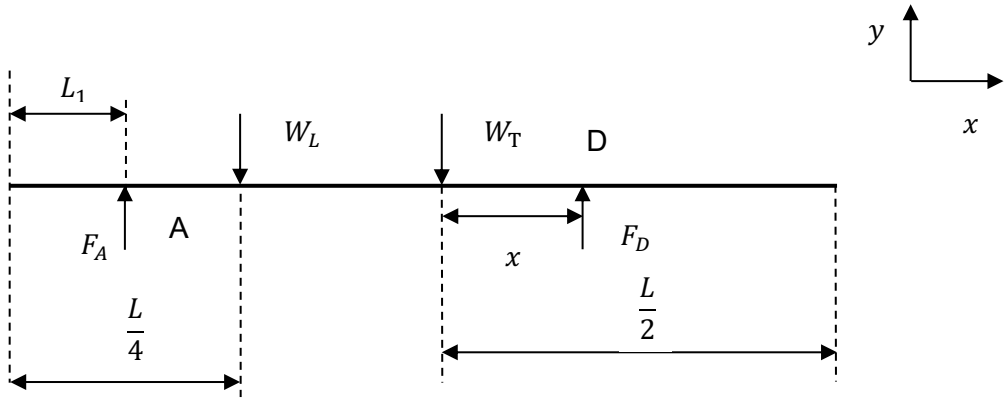


Figure 1-1: FBD of Table in Case 1

There are no forces in x-axis. Only the hinge at A can provide a force in x direction which will be equal to 0 due to absence of any other force in x direction

Taking sum of forces in y-axis

$$\sum F_y = 0$$

$$F_A + F_D - W_L - W_T = 0 \tag{1}$$

Taking sum of Moments at point A

$$\sum M_A = 0$$

$$-W_L\left(\frac{L}{4} - L_1\right) - W_T\left(\frac{L}{2} - L_1\right) + F_D\left(\frac{L}{2} + x\right) = 0$$

$$F_D = \frac{W_L\left(\frac{L}{4} - L_1\right) + W_T\left(\frac{L}{2} - L_1\right)}{\frac{L}{2} + x} \tag{2}$$

From Solidworks we find :

L_1	x	L
75mm	134.37mm	1000mm

$$F_D = 1657.29N$$

By using (1) we get –

$$F_A = 3754.71N$$

1.4.2 Case 2 – at h_max, Load at 75% of of Table length

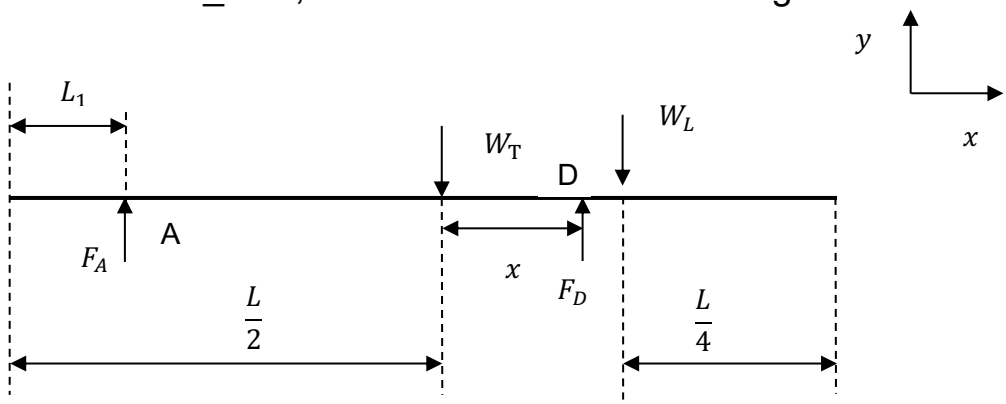


Figure 1-2: FBD of Table in Case 2

There are no forces in x-axis. Only the hinge at A can provide a force in x direction which will be equal to 0 due to absence of any other force in x direction

Taking sum of forces in y-axis

$$\sum F_y = 0$$

$$F_A + F_D - W_L - W_T = 0 \tag{3}$$

Taking sum of Moments at point A

$$\sum M_A = 0$$

$$-W_L\left(\frac{3L}{4} - L_1\right) - W_T\left(\frac{L}{2} - L_1\right) + F_D\left(\frac{L}{2} + x\right) = 0$$

$$F_D = \frac{W_L\left(\frac{3L}{4} - L_1\right) + W_T\left(\frac{L}{2} - L_1\right)}{\frac{L}{2} + x} \tag{4}$$

From Solidworks we find :

L_1	x	L
75mm	134.37mm	1000mm

By using (3) we get –

$$F_D = 5598.20N$$

$$F_A = -186.20N$$

1.4.3 Case 3 – at h_min, Load at 25% of of Table length

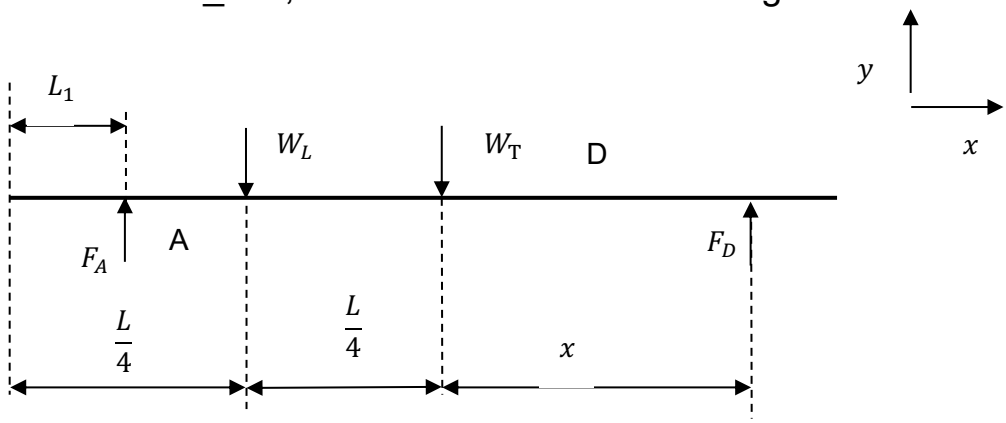


Figure 1-3: FBD of Table in Case 3

There are no forces in x-axis. Only the hinge at A can provide a force in x direction which will be equal to 0 due to absence of any other force in x direction

Taking sumof forces in y-axis

$$\sum F_y = 0$$

$$F_A + F_D - W_L - W_T = 0 \tag{5}$$

Taking sum of Moments at point A

$$\sum M_A = 0$$

$$-W_L\left(\frac{L}{4} - L_1\right) - W_T\left(\frac{L}{2} - L_1\right) + F_D\left(\frac{L}{2} + x\right) = 0$$

$$F_D = \frac{W_L\left(\frac{L}{4} - L_1\right) + W_T\left(\frac{L}{2} - L_1\right)}{\frac{L}{2} + x} \tag{6}$$

From Solidworks we find :

L_1	x	L
75mm	390.41mm	1000mm

$$F_D = 1180.73N$$

By using (5) we get –

$$F_A = 4231.27N$$

1.4.4 Case 4 – at h_min, Load at 75% of of Table length

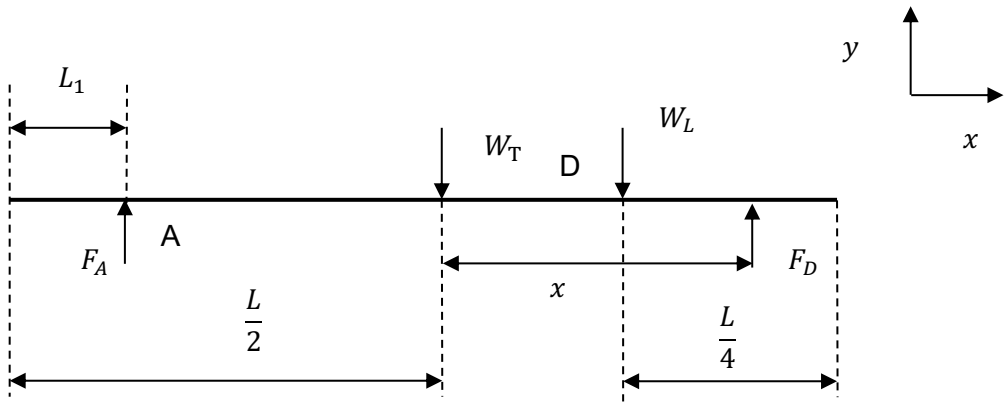


Figure 1-4: FBD of Table in Case 4

There are no forces in x-axis. Only the hinge at A can provide a force in x direction which will be equal to 0 due to absence of any other force in x direction

Taking sum of forces in y-axis

$$\sum F_y = 0$$

$$F_A + F_D - W_L - W_T = 0 \tag{7}$$

Taking sum of Moments at point A

$$\sum M_A = 0$$

$$-W_L\left(\frac{3L}{4} - L_1\right) - W_T\left(\frac{L}{2} - L_1\right) + F_D\left(\frac{L}{2} + x\right) = 0$$

$$F_D = \frac{W_L\left(\frac{3L}{4} - L_1\right) + W_T\left(\frac{L}{2} - L_1\right)}{\frac{L}{2} + x} \tag{8}$$

From Solidworks we find :

L_1	x	L
75mm	390.41mm	1000mm

$$F_D = 3988.42N$$

By using (7) we get –

$$F_A = 1423.58N$$

1.4.5 FBD of Scissor Legs AB and CD together

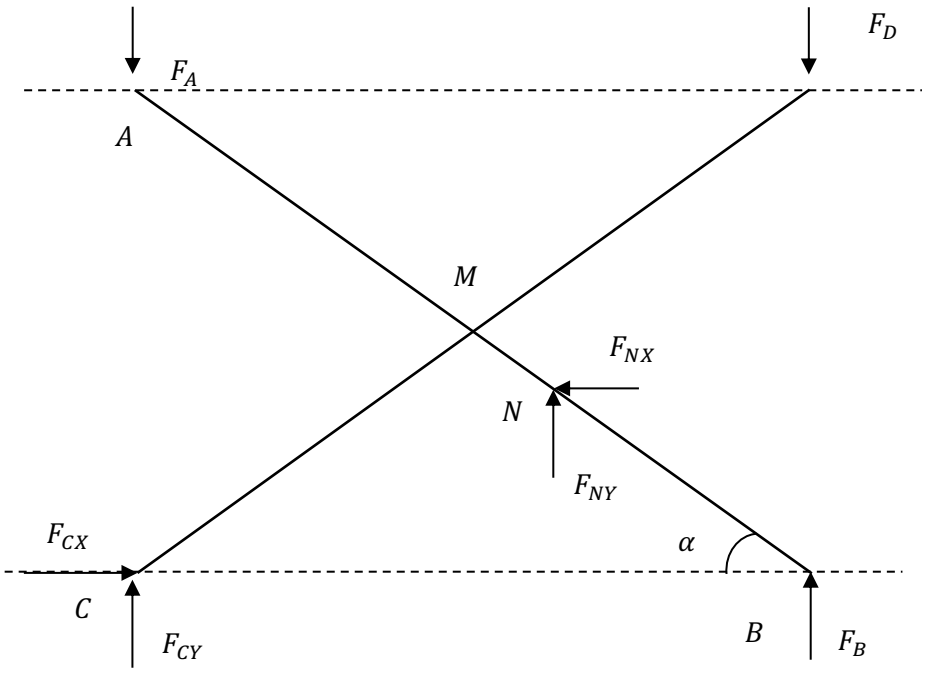
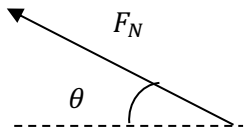


Figure 1-5: FBD of Scissor Legs AB and CD together

Let F_N be at an angle θ from the base



$$F_{NX} = F_N \cos\theta$$
$$F_{NY} = F_N \sin\theta$$

Taking sum of forces in x-axis

$$\sum F_X = 0$$
$$F_{CX} - F_{NX} = 0 \tag{9}$$

Taking sum of forces in y-axis

$$\sum F_y = 0$$
$$F_{CY} + F_B + F_{NY} - F_A - F_D = 0$$
$$F_{CY} + F_B + F_{NY} = F_A + F_D \tag{10}$$

Taking sum of Moments at C

$$\sum M_c = 0$$

$$-F_D(l\cos\alpha) + F_B(l\cos\alpha) + F_{NY}\left(l\cos\alpha - \left(\frac{l}{2} - a\right)\cos\alpha\right) + F_{NX}\left(\frac{l}{2} - a\right)\sin\alpha = 0$$

$$F_{NY}\left(l\cos\alpha - \left(\frac{l}{2} - a\right)\cos\alpha\right) + F_{NX}\left(\frac{l}{2} - a\right)\sin\alpha + F_B(l\cos\alpha) = F_D(l\cos\alpha)$$

$$F_N\left(\left(\left(\frac{l}{2} + a\right)\cos\alpha\right)\sin\theta + \left(\left(\frac{l}{2} - a\right)\sin\alpha\right)\cos\theta\right) + F_B(l\cos\alpha) = F_D(l\cos\alpha)$$

$$F_N\left(\frac{l}{2}\sin(\alpha+\theta) - a\sin(\alpha-\theta)\right) + F_B(l\cos\alpha) = F_D(l\cos\alpha) \tag{11}$$

1.4.6 Free body Diagram of Scissor Leg CD

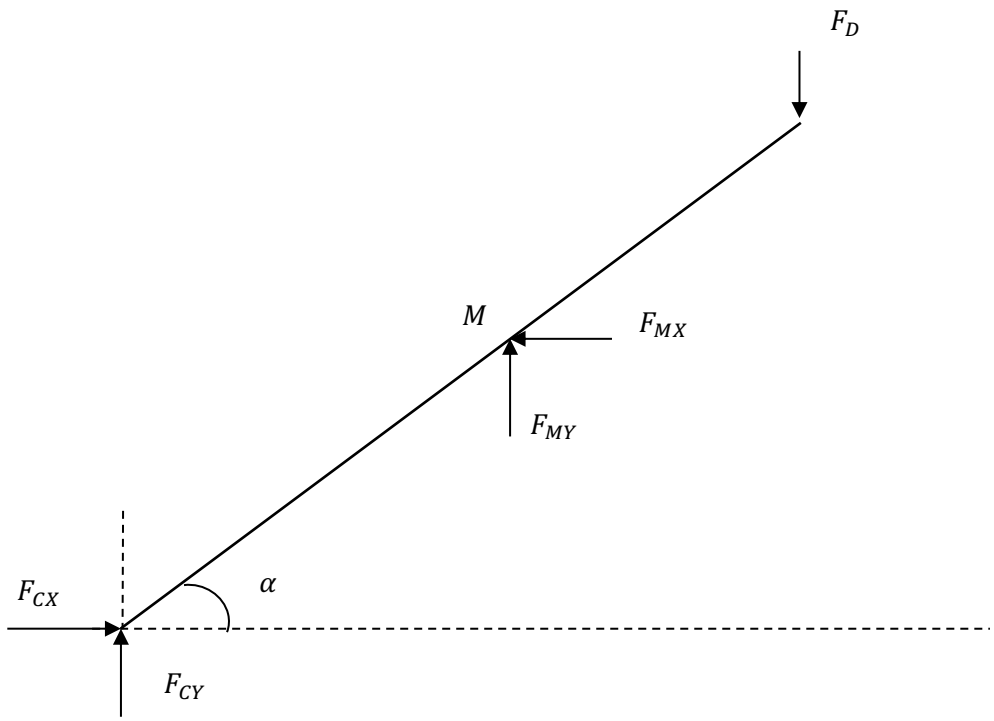


Figure 1-6: FBD of Scissor Legs CD

F_{MX} and F_{MY} are taken pin reaction forces.

Taking forces in x-axis

$$\sum F_x = 0$$

$$F_{CX} - F_{MX} = 0 \tag{12}$$

Taking forces in y-axis

$$\sum F_y = 0$$
$$F_{CY} + F_{MY} - F_D = 0$$
$$F_{CY} + F_{MY} = F_D \tag{13}$$

Taking sum of Moments at C

$$\sum M_c = 0$$
$$F_{MY}\left(\frac{l}{2}\cos\alpha\right) + F_{MX}\left(\frac{l}{2}\sin\alpha\right) - F_D(l\cos\ \alpha\ ) = 0$$

$$F_{MY}\left(\frac{l}{2}\cos\alpha\right) + F_{MX}\left(\frac{l}{2}\sin\alpha\right) = F_D(l\cos\ \alpha\ ) \tag{14}$$

In equations (9),(10),(11),(12),(13),(14) we have 6 unknowns namely F_{MX}, F_{MY}, F_N, F_B, F_{CX}, F_{CY}. Gaussian Elimination method is used to solve these 6 unknowns using 6 equations.

F_{CX}	F_{CY}	F_N	F_B	F_{MX}	F_{MY}	RHS
1	0	$-\cos\theta$	0	0	0	0
0	1	$\sin\theta$	1	0	0	$F_D + F_A$
0	0	$\left(\frac{l}{2}\sin(\alpha+\theta) - a\sin(\alpha-\theta)\right)$	$l\cos\alpha$		0	$F_D(l\cos\alpha)$
1	0	0		-1	0	0
0	1	0		0	1	F_D
0		0		$\left(\frac{l}{2}\sin\alpha\right)$	$\left(\frac{l}{2}\cos\alpha\right)$	$F_D(l\cos\ \alpha\ )$

Only F_A, F_D, α and θ are changing in all the 4 different Cases. To obtain the values of the 6 unkowns, the value of α and θ are taken from SolidWorks models as per respective Cases and F_A, F_D have already been calculated previously for each Case.

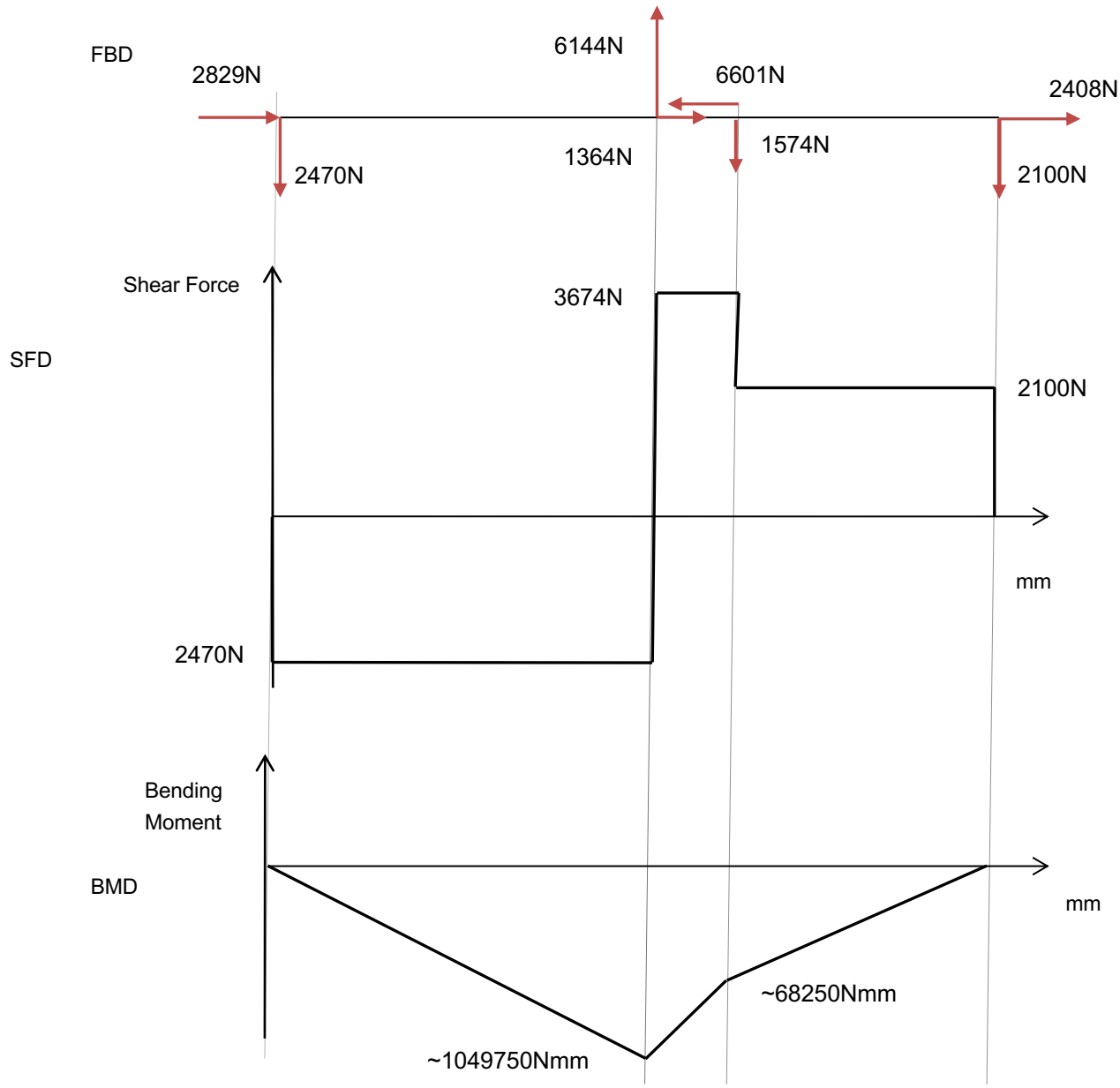
1.4.7 Case 1

α	θ	F_D	F_A
$48.85°$	$35.44°$	$1657.29N$	$3754.71N$

After solving the gaussian equations above, we get –

F_{CX}	F_{CY}	F_N	F_B	F_{MX}	F_{MY}
$5524.24N$	$4674.94N$	$6786.53N$	$-3192.34N$	$5524.23N$	$-3017.65N$

Scissor leg pair AB



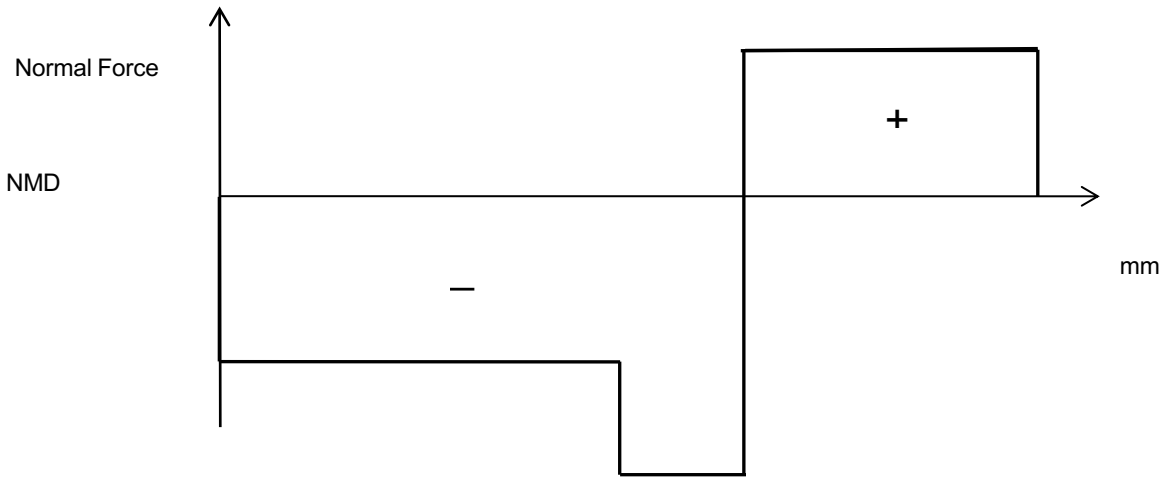
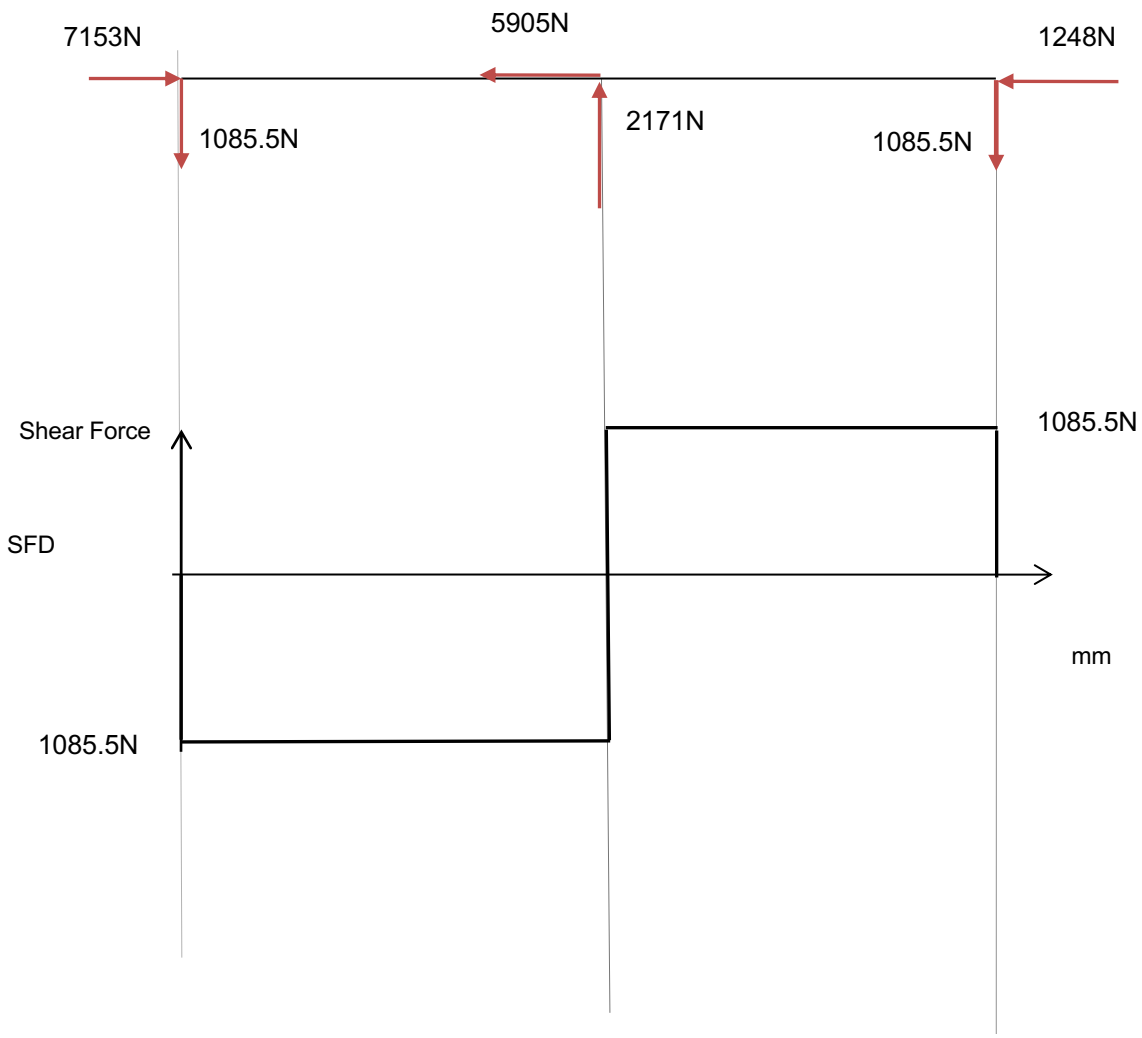


Figure 1-7: FBD, SFD, BMD and NFD of Scissor Legs AB

Scirror leg pair CD

FBD



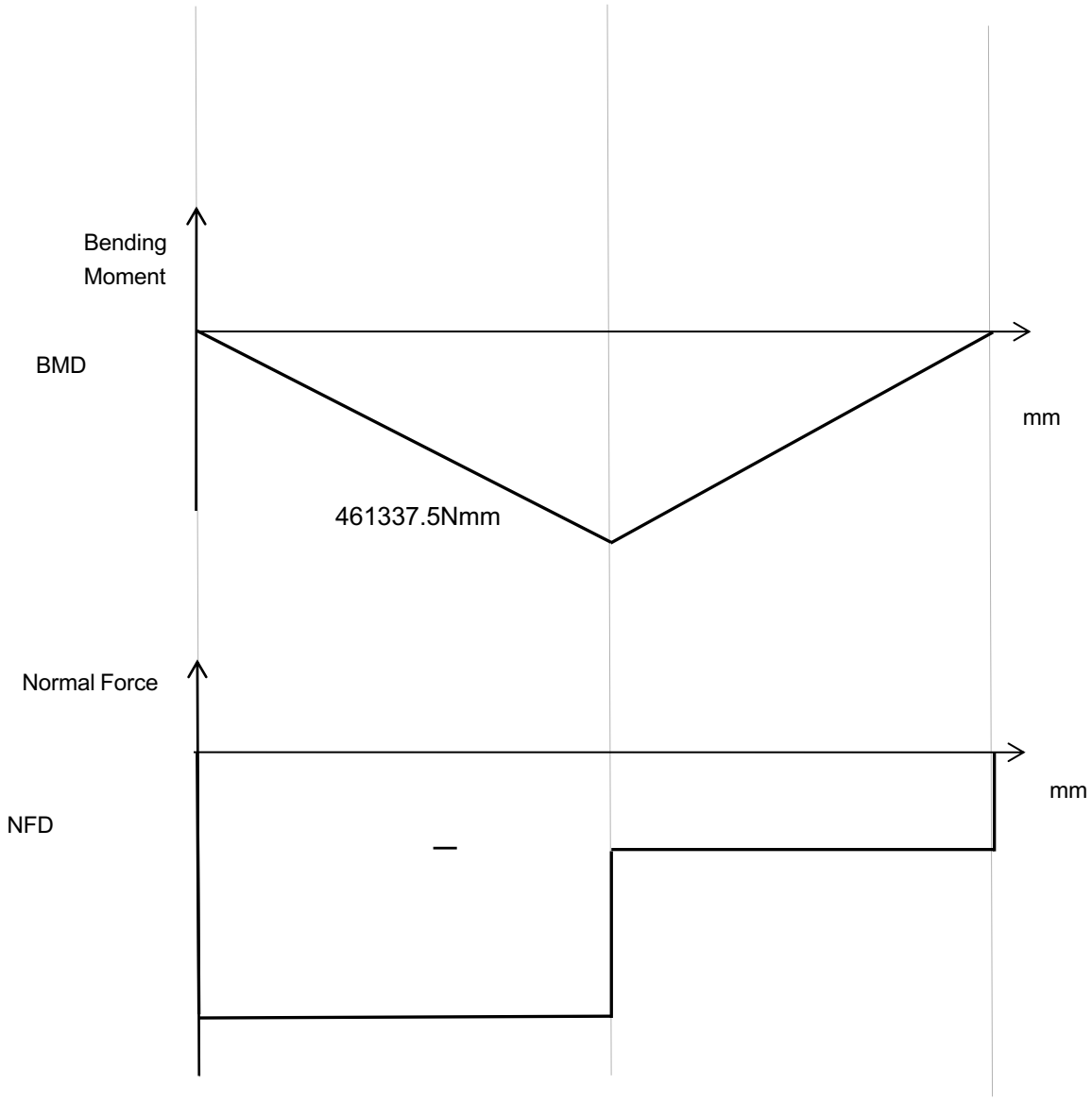


Figure 1-8: FBD, SFD, BMD and NFD of Scissor Legs CD

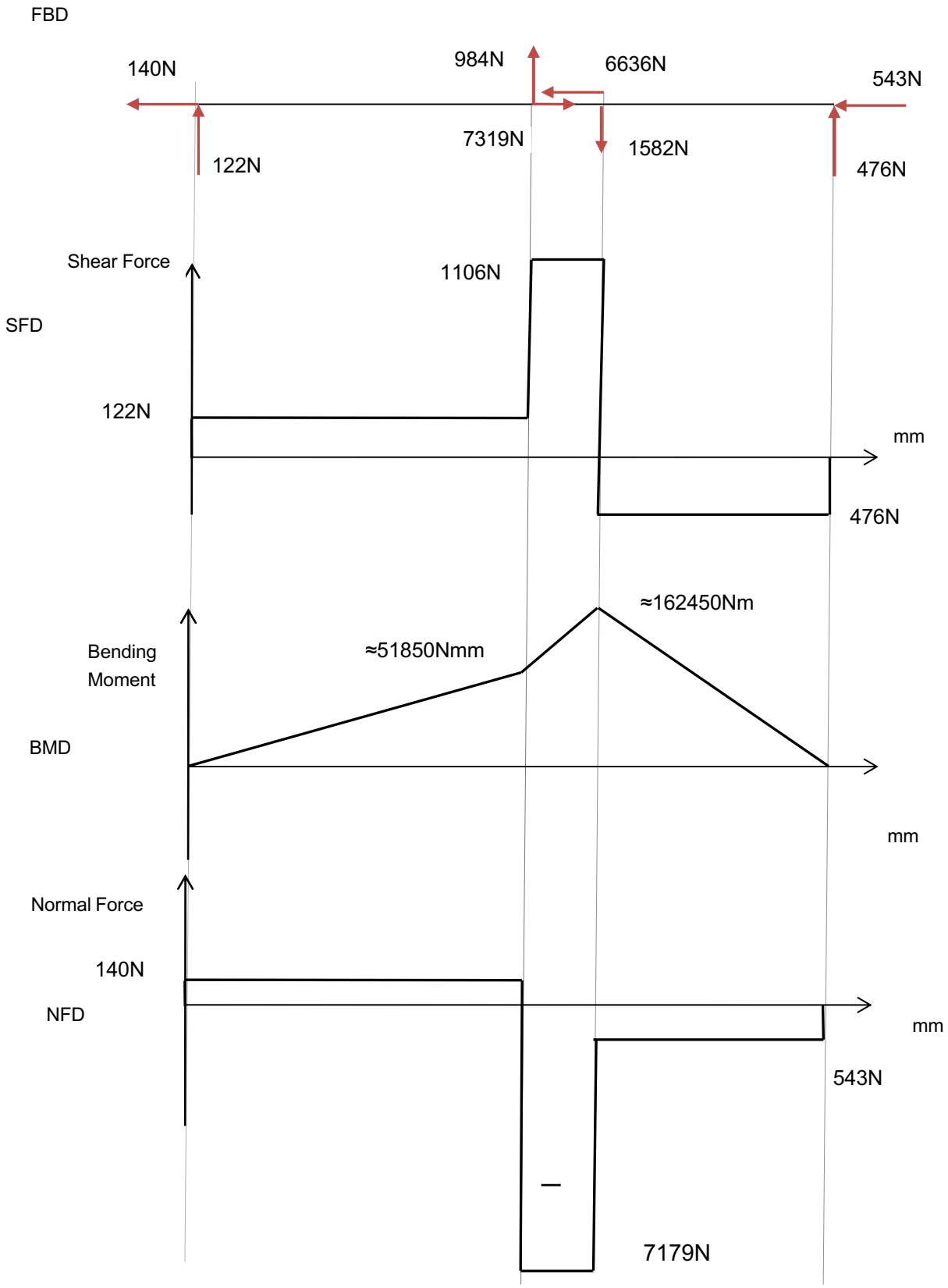
1.4.8 Case 2

α	θ	F_D	F_A
$48.85°$	$35.44°$	$5598.20N$	$-186.20N$

After solving the gaussian equations above, we get –

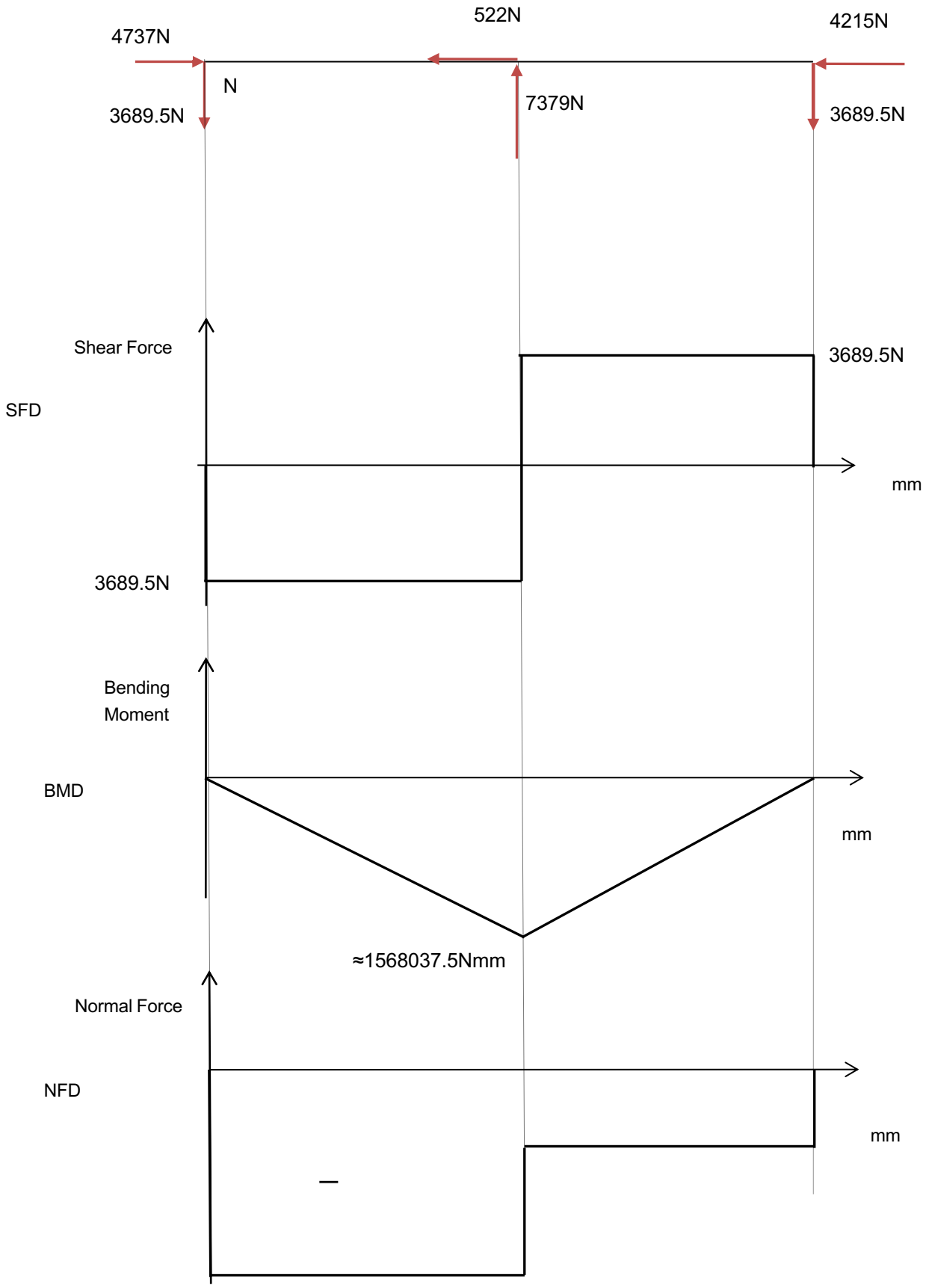
F_{CX}	F_{CY}	F_N	F_B	F_{MX}	F_{MY}
$5553.10N$	$738.78N$	$6822.00N$	$723.28N$	$5553.10N$	$4859.41N$

Scissor leg AB



Scissor leg Pair CD

FBD



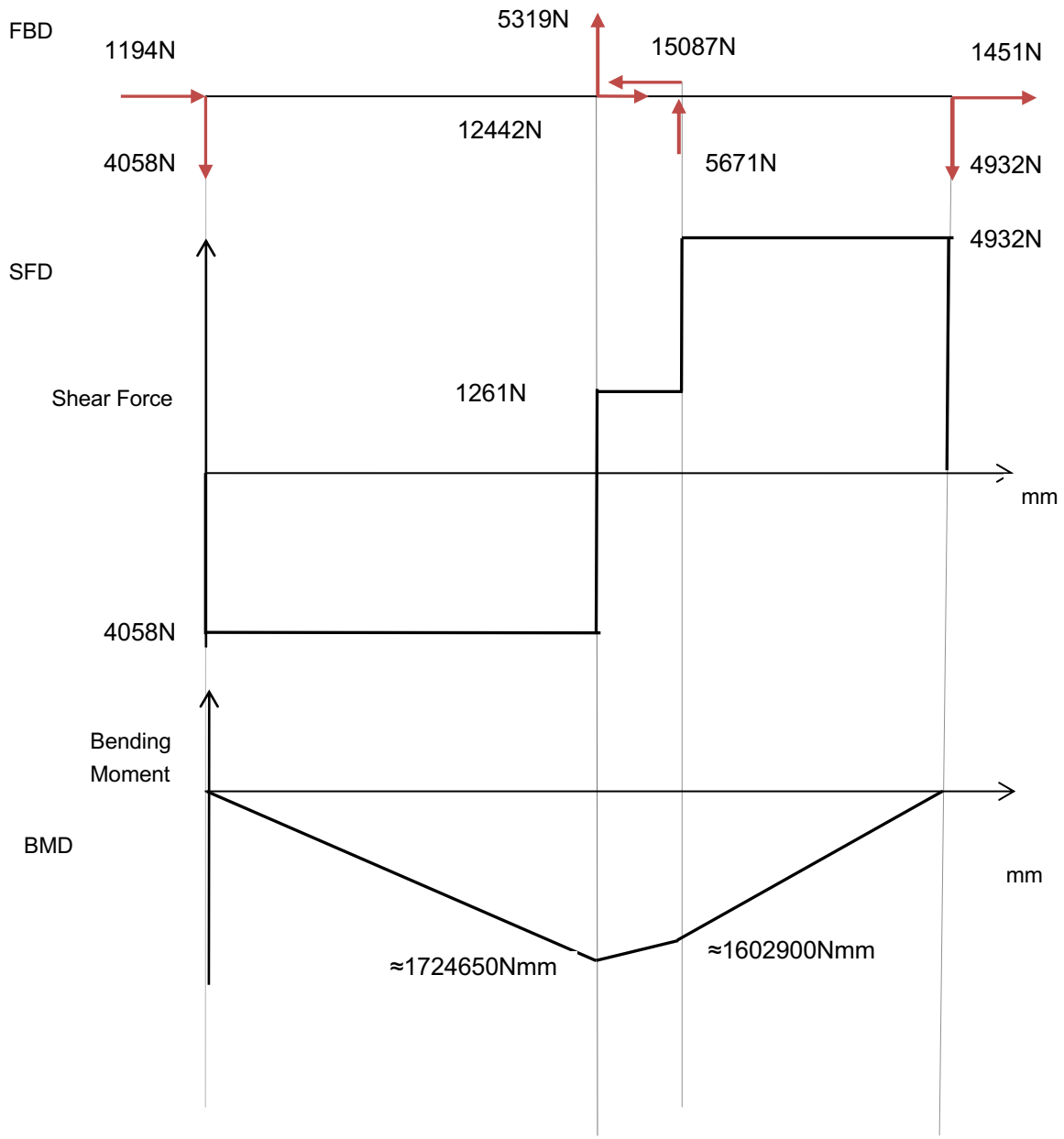
1.4.9 Case 3

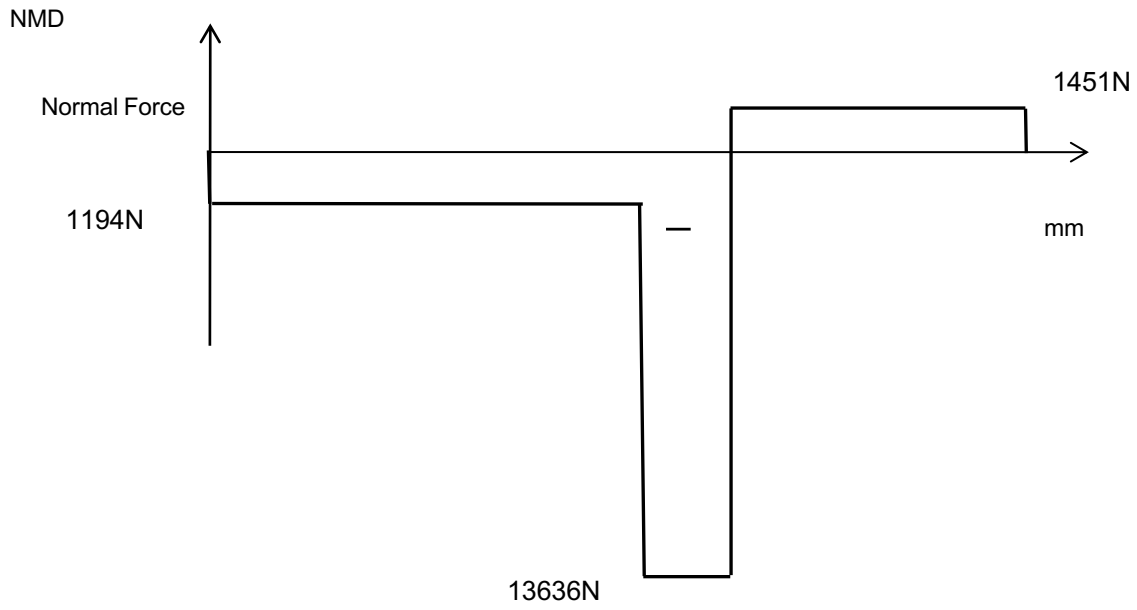
α	θ	F_D	F_A
$16.4°$	$30.1°$	$1180.73N$	$4231.27N$

After solving the gaussian equations above, we get –

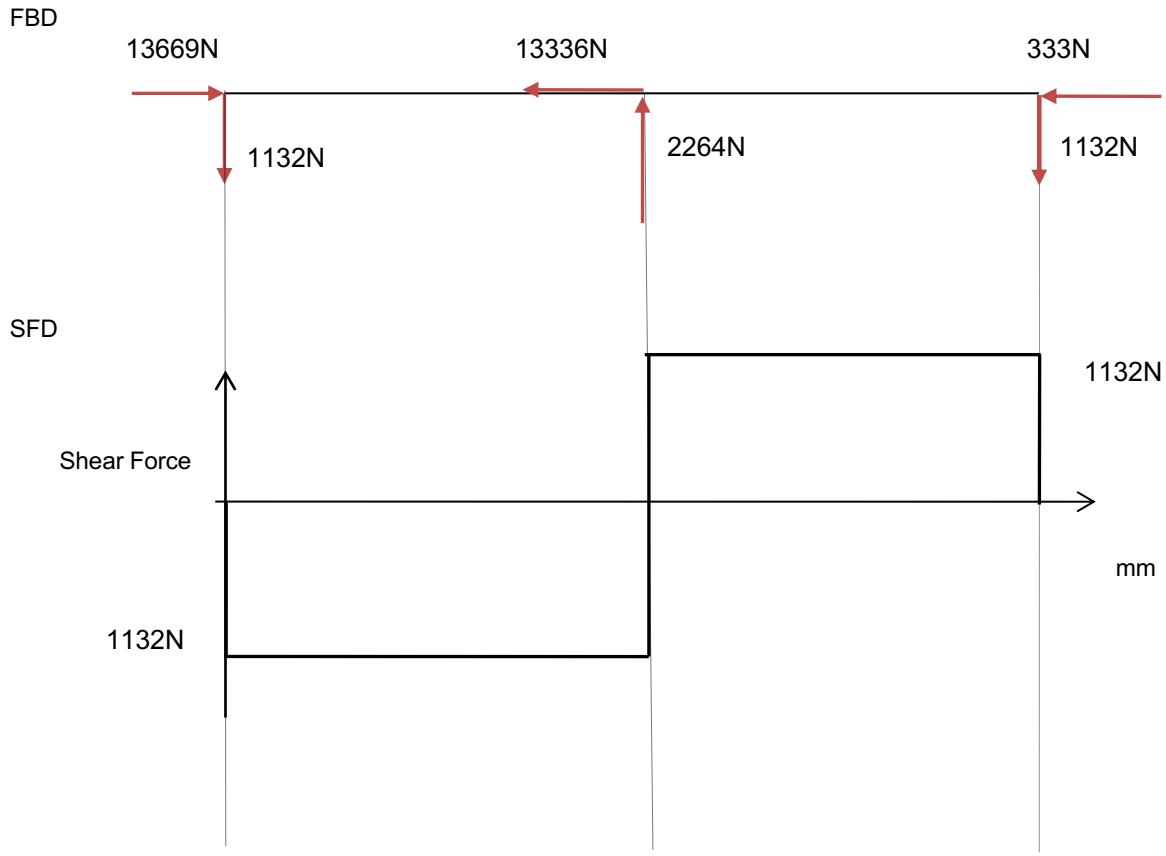
F_{CX}	F_{CY}	F_N	F_B	F_{MX}	F_{MY}
$13433.39N$	$2773.12N$	$15529.92N$	$-5141.62N$	$13433.39N$	$-1592.40N$

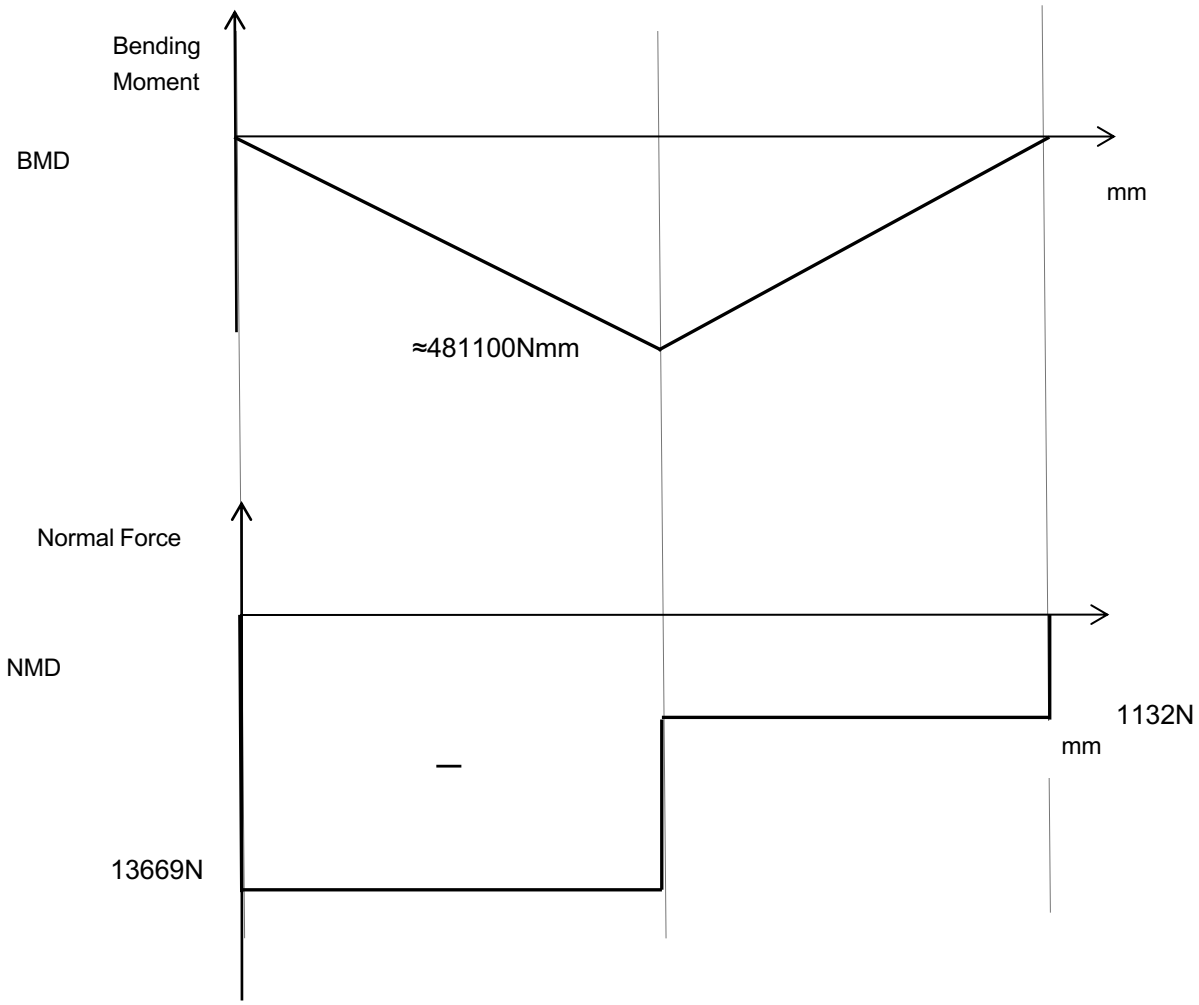
Scissor leg AB





Scissor leg Pair CD





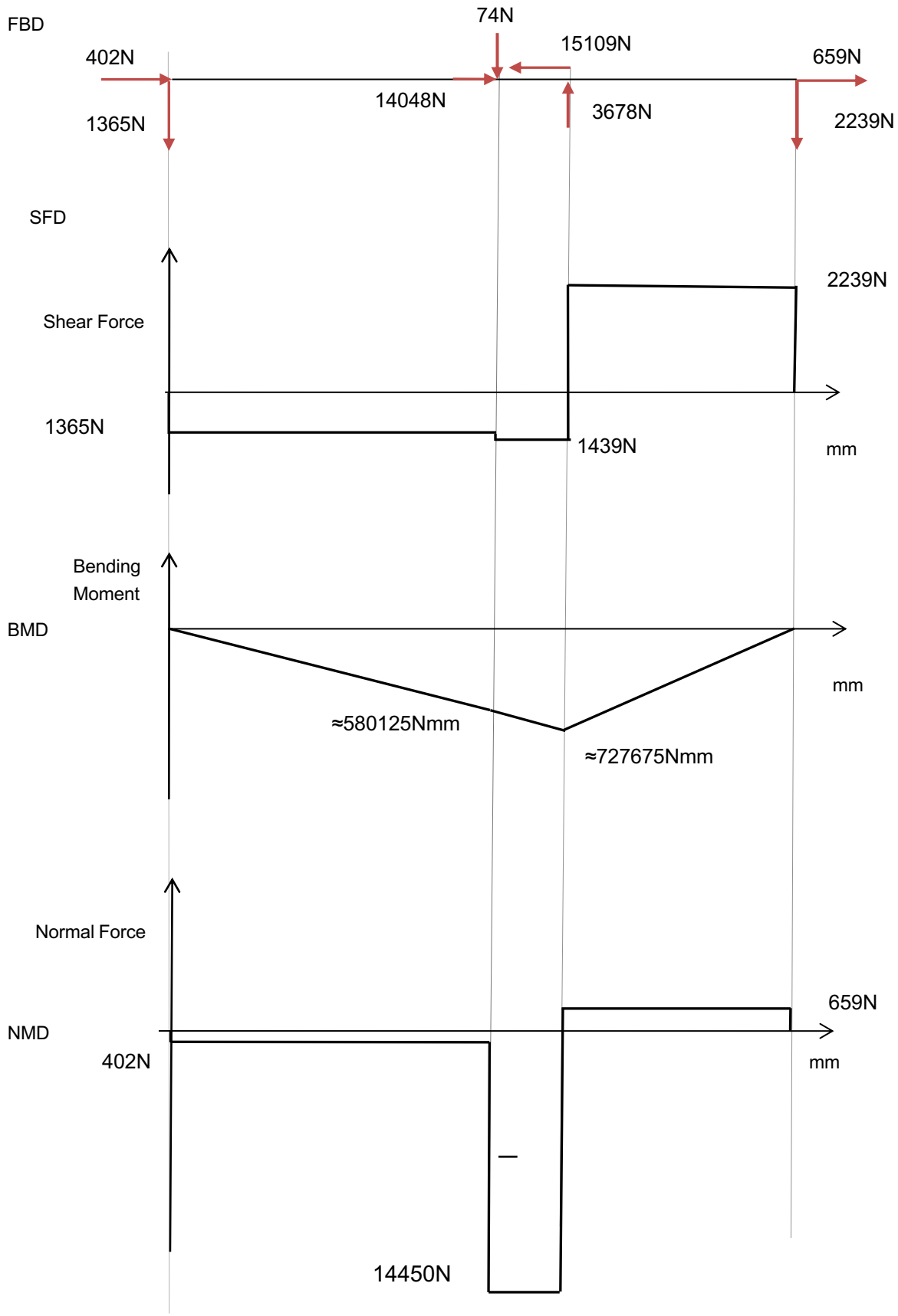
1.4.10 Case 4

α	θ	F_D	F_A
$16.4°$	$30.1°$	$3988.42N$	1423.58

After solving the gaussian equations above, we get –

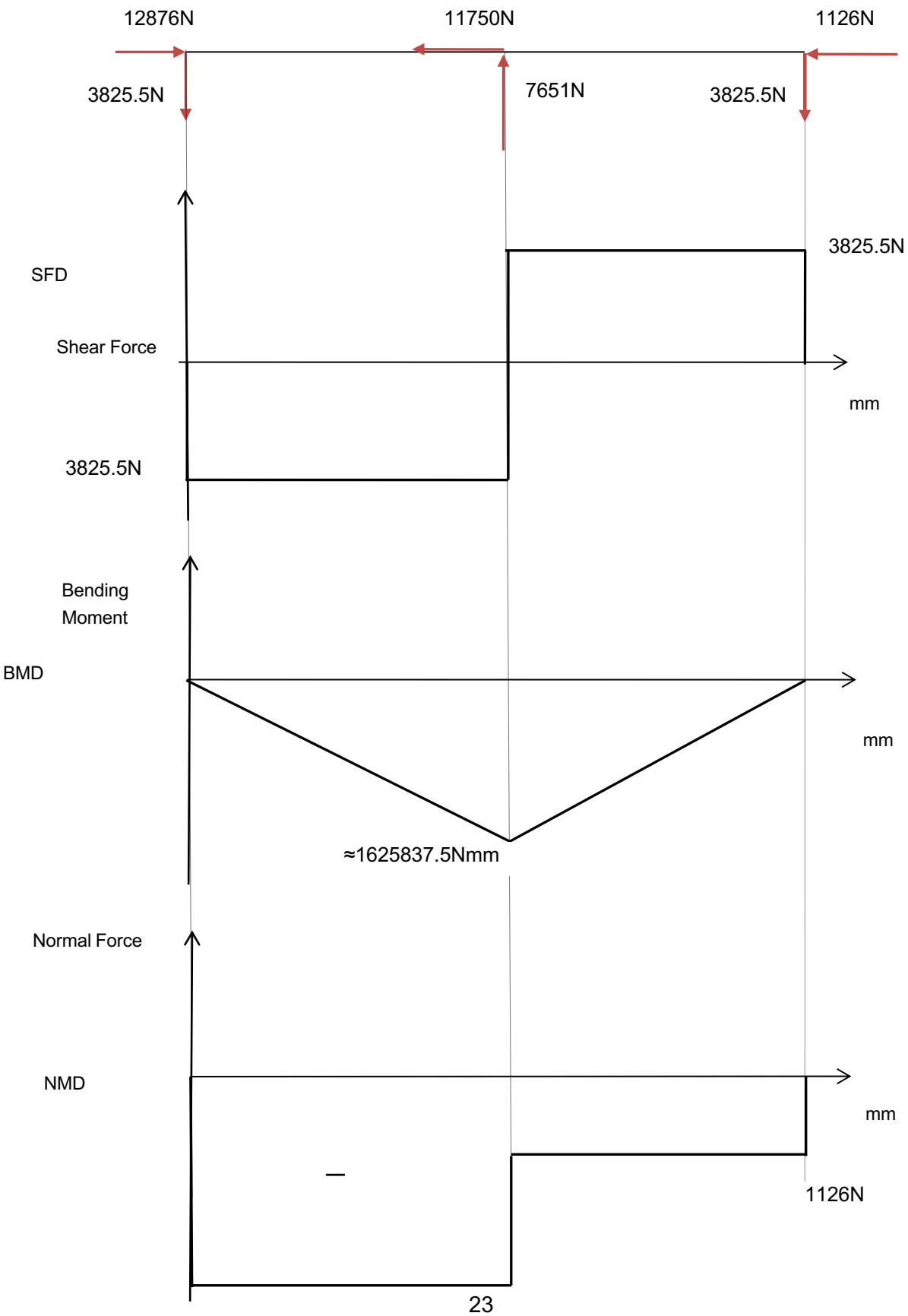
F_{CX}	F_{CY}	F_N	F_B	F_{MX}	F_{MY}
$13433.61N$	$-34.61N$	$15530.19N$	$-2334.01N$	$13433.61N$	$4023.03N$

Scissor leg AB



Scissor leg Pair CD

FBD



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2 Stress Analysis

The structure's calculations of stresses play a very important role in the construction, since the reliability, safety and effective work of the whole system depends on the outcome of these calculations and their accuracy.

2.1 Stress calculation

From the FBD, SFD and BMD for all Cases, it can be determined that Case 3 has the maximum Bending Moment (M_B) and maximum Shear Force (P_s) in scissor leg pair AB. So, if the design can withstand these forces and moments in this Case then, the design can withstand in other Cases too.

2.1.1 Scissor Legs AB

As we have done the calculation for pair of legs, we will devide the forces and moments by a factor of 2 so that we can get forces and moments on each leg individiually.

Point M is considered for calculation as this is where there would be maximum chances of breakage as maximum M_B and Normal Stress (N) is acting here. Even though shear force is not maximum at this point, we will consider it as it does not have significant impact on the overall calculation. If fracture occurs, it will be because of bending stress and not shear stress so, the point at which bending stress is maximum is considered.

$$M_{B_{per},Max} = \frac{1724650}{2}\ Nmm = 862325\ Nmm$$

$$P_{per,Max} = \frac{4058}{2} N = 2029N$$

$$N_{per,Max} = \frac{13636}{2} N = 6818\ N$$

$$\frac{d}{w} = 0.4$$

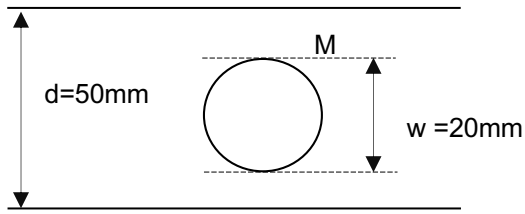

Figure 2-1: Detailed view of point M

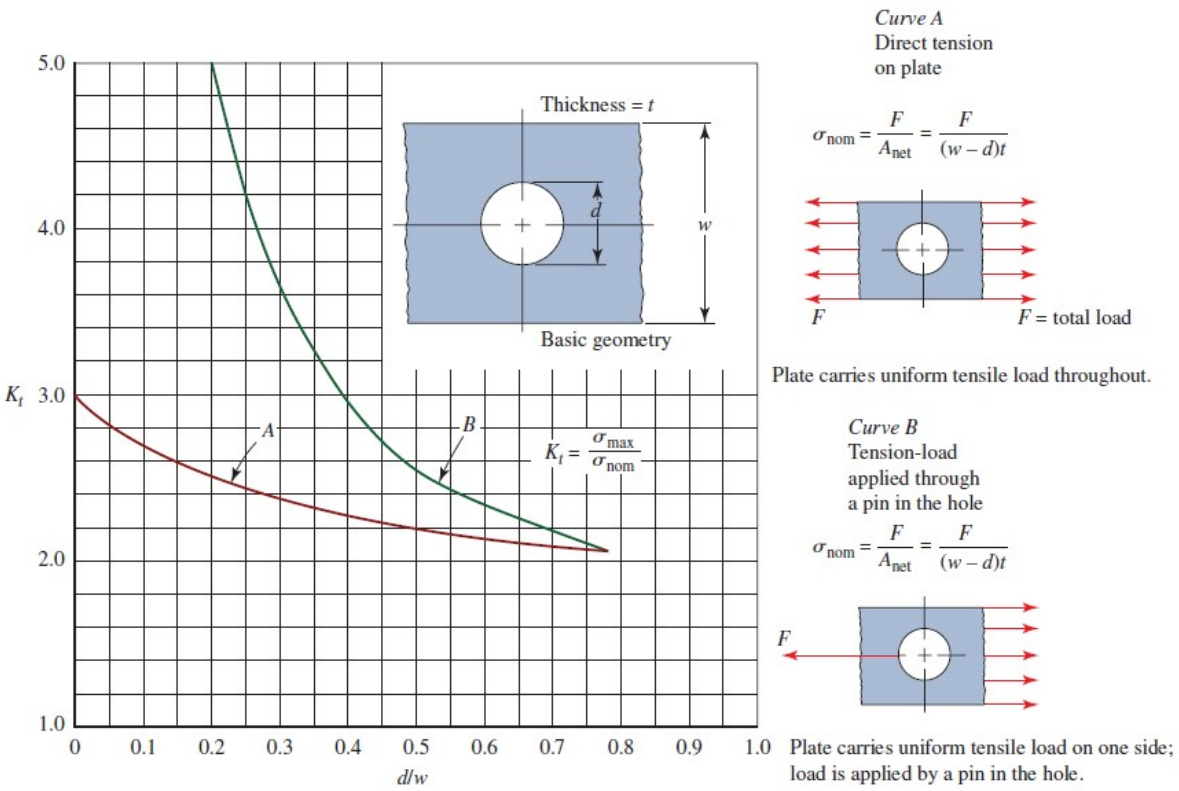

FIGURE A18–4 Flat plate with a central hole in tension

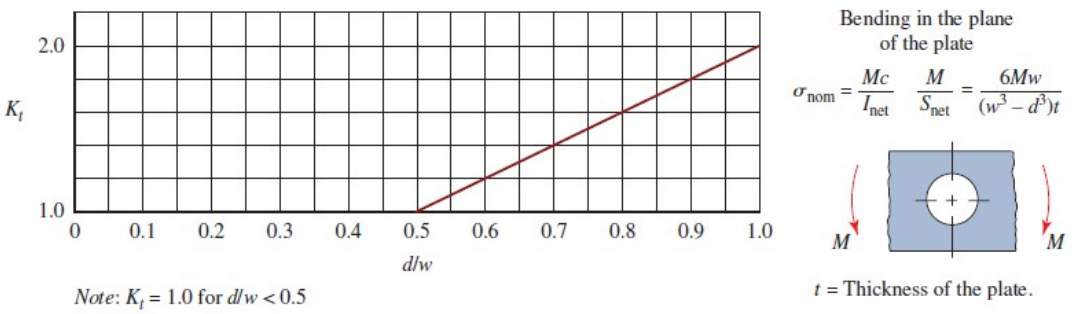

FIGURE A18–5 Flat plate with a central hole in bending

Figure 2-2: Reference sheet for stress analysis given by Professor Schacky

Refering to Figure 2-2,

K_t factor for Normal Stress (σ_N) for curve B in the section Figure A18-4 is 2.95 and for Bending Stress (σ_B) in section Figure A18-4 is 1.

2.1.2 Calculation for σ_N

$$\sigma_N = \frac{N \cdot K_t}{A} = \frac{N_{per,Max} \cdot K_t}{(w-d)t}$$

$$= \frac{(6818\,N)(2.95)}{(50mm - 20mm)(15mm)}$$

$$= 44.70\,\frac{N}{mm^2}$$ (compressive)

2.1.3 Calculation for σ_B

$$\sigma_B = \frac{M \cdot c}{I} = \frac{6 \cdot M_{B_{per},Max} \cdot w}{(w^3 - d^3)t}$$

$$= \frac{6 \cdot (862325\,Nmm)(50mm)}{((50mm)^3 - (30mm)^3)(15mm)}$$

$$= 147.40\,\frac{N}{mm^2}$$

For σ_B is K_t factor 1.

2.1.4 Calculation for τ_S

$$\tau_S = \frac{P}{A} = \frac{P_{per,Max}}{(w-d)t}$$

$$= \frac{2029\,N}{(50mm - 20mm)(15mm)}$$

$$= 4.51\,\frac{N}{mm^2}$$

2.1.5 Calculation for σ_{eq}

As the material used for the design is S355J2G3 is ductile and there is shear force not dominant, Von – Mises Hypthesis id used to calculate σ_{eq}.

$$\sigma_{eq} = \sqrt{\sigma_x^2 + 3\tau_{xy}^2} = \sqrt{(\sigma_N + \sigma_B)^2 + 3\tau_S^2}$$

$$= \sqrt{\left(147.40\frac{N}{mm^2} + 44.70\frac{N}{mm^2}\right)^2 + 3 \cdot \left(4.51\frac{N}{mm^2}\right)^2}$$

$$= 192.26\frac{N}{mm^2}$$

2.1.6 Safety check

For safety reasons, the safety factor is 1.5

$S = 1.5$

For S355J2G3, the R_e is -

$R_e = 315\frac{N}{mm^2}$

$$\sigma_{allow} = \frac{R_e}{S} = \frac{315}{1.5}\frac{N}{mm^2}$$

$$= 210\frac{N}{mm^2}$$

As, $\sigma_{allow} > \sigma_{eq}$

The design can safely handle 5 KN load in all cases.

3 Weld Analysis

The only part which is welded is clevis of the hydraulic piston on the square tube of scissor legs AB. Double Fillet Weld (Mitre) is considered on the clevis as fillet weld is better for T joints than butt weld. Also fillet weld is more economical. Runout is considered for the double fillet weld. Weld material is chosen to S355 as it has good weldability and a normal quality weld is taken.

Maximum piston forces are seen in Case 4 ($F_N = 15530.19\ N$)and Case 3 ($F_N = 15529.92\ N$). As the valves are so close to each other, $F_N = 15531\ N$ is taken.

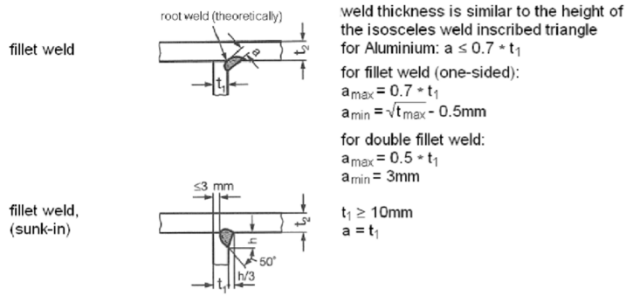

Figure 3-1: Reference to Weld formulas []

For double fillet weld:

$a_{Max} = 0.5\ t_1$
$a_{Min} = 3mm$

For this design

$a_{Max} = 0.5\ (15mm)$
$a_{Max} = 7.5mm$

$a = 7.5mm$ is considered
As runout is taken for the weld,
$A_{weld} = a \cdot b$

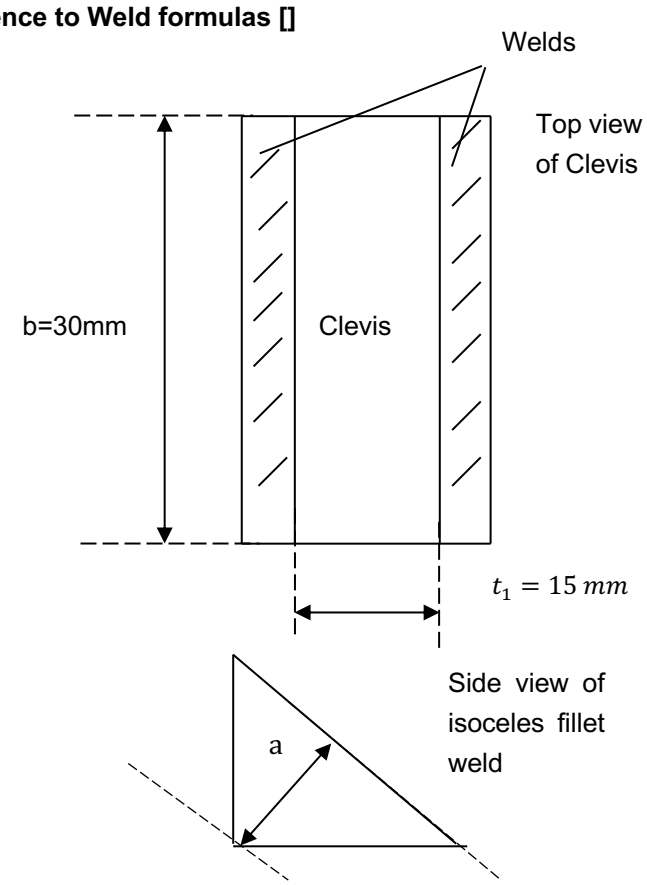

Figure 3-2: Side View of Weld and Top View of Clevis

3.1.1 Calculation for τ_S

$$\tau_S = \frac{\left(\frac{F_N}{2}\right)\cos(\theta - \alpha)}{2 \cdot A_{weld}}$$
$$= \frac{15531\cos(13.71)\ N}{4 \cdot (7.5mm)(30mm)}$$
$$= 16.76 \frac{N}{mm^2}$$

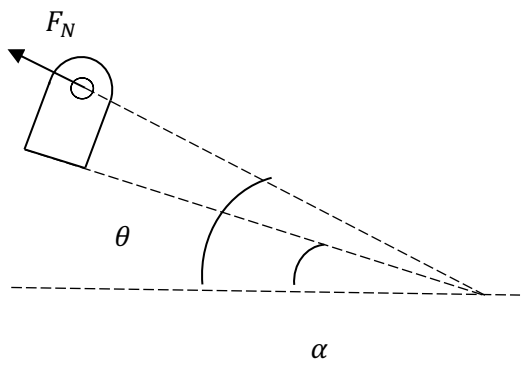

Figure 3-3: Attacking angle of piston on clevis

3.1.2 Calculation for σ_N

$$\sigma_N = \frac{\left(\frac{F_N}{2}\right)\sin(\theta - \alpha)}{2 \cdot A_{weld}}$$
$$= \frac{15531\sin(13.71)\ N}{4 \cdot (7.5mm)(30mm)}$$

$$= 4.08 \frac{N}{mm^2}$$

3.1.3 Calculation for σ_B

$$\sigma_B = \frac{M \cdot c}{I} = \frac{\left(\frac{F_N}{2}\right)\cos(\theta - \alpha) \cdot h \cdot \left(\frac{b}{2}\right)}{\frac{1}{12} \cdot (b^3 a) \cdot 2}$$
$$= \frac{6 \cdot (226327.3\ Nmm)(15mm)}{((30mm)^3(7.5mm))}$$

$$= 100.59 \frac{N}{mm^2}$$

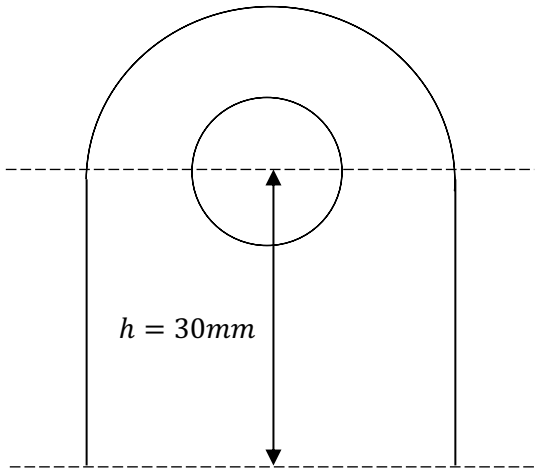

Figure 3-4: Side View of Clevis

3.1.4 Calculation for σ_{eq}

As weld is brittle, we use Maximum Normal Stress Hypothesis to calculate σ_{eq}.

$$\sigma_{eq,weld} = \frac{1}{2}\left(\sigma_x + \sqrt{\sigma_x^2 + 4\tau_{xy}^2}\right)$$

$$\sigma_x = \sigma_B + \sigma_N$$

$$\sigma_{eq} = \frac{1}{2}\left(\left(100.59\,\frac{N}{mm^2} + 4.08\frac{N}{mm^2}\right) + \sqrt{\left(100.59\frac{N}{mm^2} + 4.08\frac{N}{mm^2}\right)^2 + 4\cdot\left(16.76\frac{N}{mm^2}\right)^2}\right)$$

$$= 105.38\frac{N}{mm^2}$$

3.1.5 Safety check

kind of weld	kind of stress	perfor-mance class	load case					
			static		pulsating		alternating	
			material					
			S235	S355	S235	S355	S235	S355
butt joint with sealing run	tension compression bending	B	160	220	110	130	55	65
		C	130	175	85	105	45	50
		D	110	155	75	90	40	45
	shearing load	B	100	140	70	80	35	40
		C	80	110	55	65	30	32
		D	70	100	50	55	25	28
butt joint with-out sealing run	tension compression bending	B	140	180	95	100	45	50
		C	110	145	75	80	35	40
		D	100	125	65	70	32	35
	shearing load	B	90	110	60	70	30	35
		C	70	85	50	55	25	30
		D	60	75	40	50	20	25
flat face fillet weld	all	B	90	110	60	70	30	35
		C	70	85	50	55	25	30
		D	60	75	40	50	20	25
concave fillet weld	all	B	120	150	75	90	40	45
		C	95	120	60	70	30	35
		D	85	100	50	60	25	30
double flat face fillet weld and circular fillet weld	all	B	140	190	90	120	50	55
		C	110	150	70	95	40	45
		D	100	130	60	85	35	40

Performance classes for the weld:

B: high quality
If a failure of a weld would lead to endangerment of persons or machine, for high dynamic loads

C: normal quality
For medium stresses, if a failure of the weld does not influence the main function of the machine

D: low quality
For low stresses, if the a failure of the weld has no influence on the function of the machine

Figure 3-5: Allowable stress chart for weld []

Referreing to Figure 3-2 for static, S355 material weld of normal quality

$$\sigma_{allow,weld} = 150\frac{N}{mm^2}$$

As, $\sigma_{allow,weld} > \sigma_{eq,weld}$

The welded portion of Clevis on the square tube on scissor legs AB will not break under any of load the load Cases.

4 Assembly Drawing

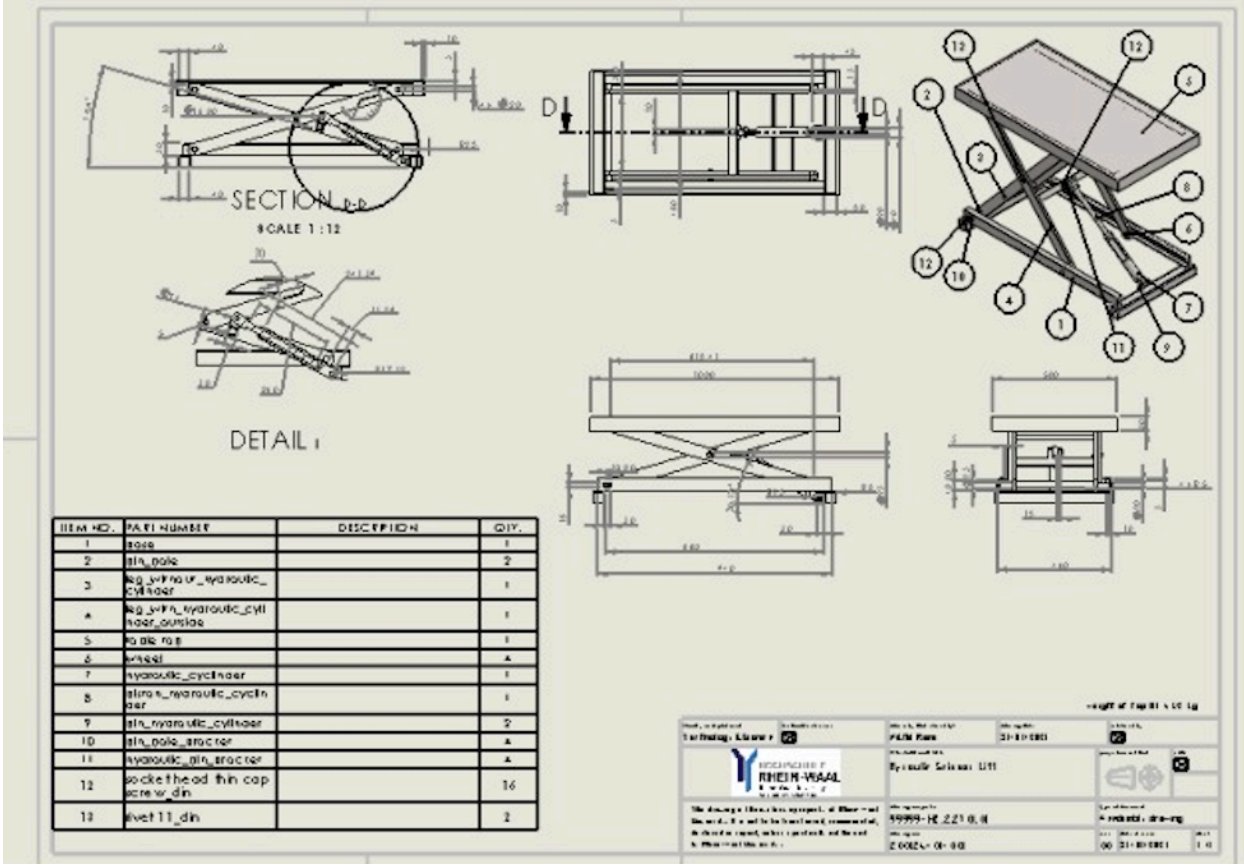

Figure 4-1: Assembly Drawing

5 Refrences

1. Documents for “Advanced Engineering Design” study material, Rhein Waal University of Applied Sciences