Buskerud and Vestfold University College

CRANE MECHANICAL

BACHELOR PROJECT

Mechanical Engineering

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Printed: November 2014

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ABSTRACT:

This report explains the structural and mechanical design of a crane located in a offshore platform.

The introduction summarizes the two main parts of the project, the structural calculus of the crane and the mechanical design of the equipment. The report continues with the structural calculus of the crane, both theoretical and using a software. Following, the structural calculus and the mechanical design of the equipment are detailed. Finally, the conclusions show that, by following the mentioned steps the objectives have been achieved. The integrity of the crane and the possibility to be built have been demonstrated. Regarding to the mechanical design, the suitability of the equipment has been validated and the conditions required to meet by the gear box determined.

The bibliography and the attachments can be found at the end.

1. INTRODUCTION:

This project deals with the structural calculus of a mechanical crane, and the dimensioning of the mechanical equipment. The crane is located in an offshore platform and is used to lift boats.

This report is divided in two parts: the structural calculus of the crane and the mechanical dimensioning of the equipment. The conclusions of the report are detailed to finish it.

1.1 Objectives of the structural part:

The objectives of this part are to calculate the forces and stress in the crane and to determine if the design of the crane and the material are appropriated.

To achieve the objectives the steps followed were: 1. Determine the proprieties of the bars (inertia moment and area) which are necessary to carry the rest of the calculations required, 2. Determine the determinacy, 3. Calculate the forces in the structure, 4. Draw the structure diagrams, 5. Calculate the necessary strain and stress and 6. Check the total stress and utilization U.

1.2 Objectives of the mechanical design:

The objectives of the second part are the calculus and dimensioning of the mechanical equipment.

The steps in the second part were: 1. Calculate the engine power, 2. Determinate the wire-drum speed, 3. Obtain the speed of the pulleys, 4. Determinate the gear ratio between the engine and the small pulley and 5. The incoming speed on the gearbox, 6. Calculate the speed ratio in the gear box. 7. Dimension the incoming gear, 7. Calculate the differences when the engine effect is reduced.

2. STRUCTURAL CALCULUS OF THE CRANE:

The crane is made of steel whit a S_Y = 355 MPa , and with a Working Load Limit of $5*10^3$ Kg. It means that it is capable of lifting a mass m=5 tonnes in accordance to the NORSOK offshore rules. The steel wire is connected to a winch, running through a frictionless hoist as can be seen in the annexe number one.

The structure of the crane can be discretized as an structure of four bars and four nodes as it appears in the *Figure 2.1*.

The calculus are handmade. Nevertheless, some results have been checked using a simulation software based in the direct stiffness method.

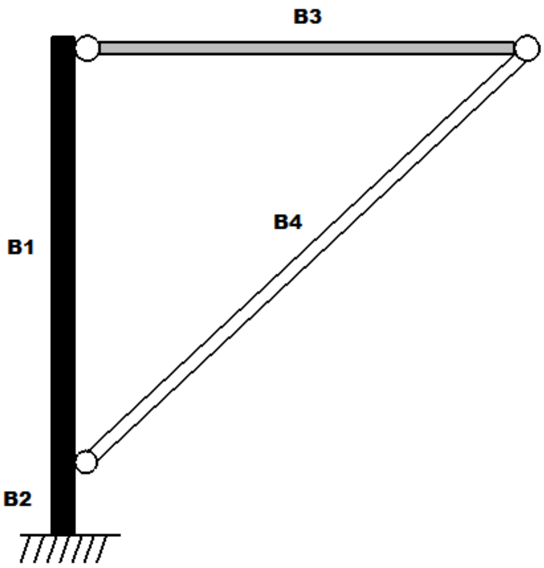


Figure 2.1: Discretized structure

The B2 and B1 bars are the pillar of the crane, made of a pipe with Ø=600 mm and thickness=10 mm. The bar B3 has a diameter of 20 mm, Length L=5m and the bar B4 has Ø=200 mm and thickness=5mm.

The model used for de simulation with the software is shown in the Figure 2.2:

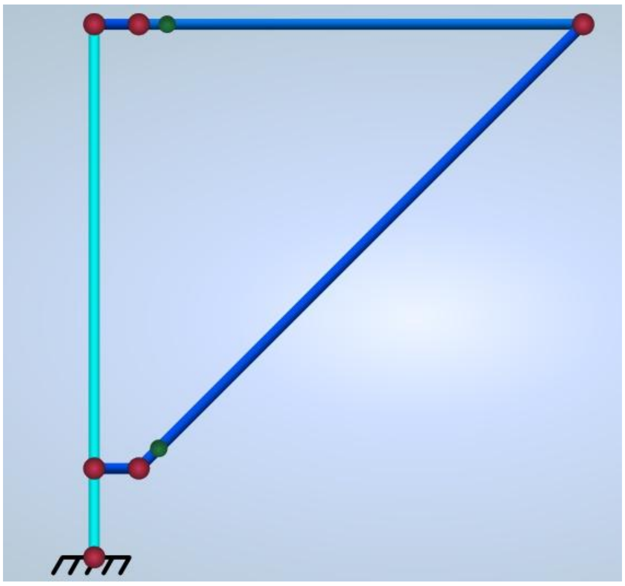


Figure 2.2: Structure model used for simulation

Two additional bars are required in the model to simulate the two small bars resulting from the union between the pillar and the other bars.

This two small bars are modelled using the same properties of the B4 bar, because the lack of information about them. However, this approximation is not so far from the reality.

2.1 Proprieties of the bars:

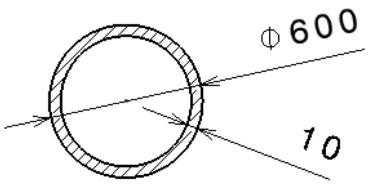
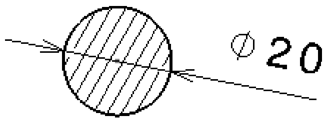


Fig 2.3 a): B1 and B2 bars section

B1 and **B2** bars:

$\mathbf{A_1}=\mathbf{A_2}= \pi(R^2-r^2) =\pi(300^2-290^2)= 18535{,}4\ mm^2$

$\mathbf{I_1}=\mathbf{I_2}= \pi/4(R^4-r^4) =\pi/4(300^4-290^4)= 806753139{,}5\ mm^4$

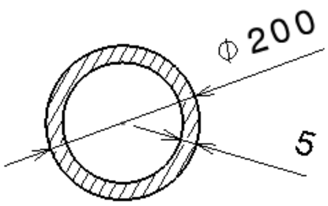


B3 bar:

$\mathbf{A_3}$= $\pi r^2 = \pi 10^2$= 314,16mm^2

$\mathbf{I_3}$= $(\pi/4)r^4 = (\pi/4)(10^4)$= 7853,98 mm^4

Fig 2.3 b): B3 bar section



B4 bar:

$\mathbf{A_4}$= $\pi(R^2\text{-}r^2) = \pi(100^2\text{-}95^2)$= 3063,05 mm^2

$\mathbf{I_4}$= $\pi/4(R^4\text{-}r^4) = \pi/4(100^4\text{-}95^4)$= 14568645,06 mm^4

Fig 2.3 c): B4 bar section

2.2. Degree of indeterminacy:

It is possible to know if the structure is statically determinate or indeterminate by applying the following expression:

$$Di = (3 \cdot B) - (3 \cdot R + l + l_s) \qquad \textbf{\textit{(Eq.2.1)}}$$

B = number of bars

R = number of reactions

l = number of freedoms in the nodes

l_s = number of freedoms in the supports

Substituting values in the *Eq.2.1* expression *:*

$$Di = (3 \cdot 4) - (3 \cdot 3 + 3 + 0) = 0$$

This structure is therefore statically determinate allowing to obtain the forces by means of equilibrium equations.

2.3. Calculus of the forces in the structure:

It is possible to decompose the force of the weight in two components, one vertical and one horizontal as is showed in the *Figure 2.4*

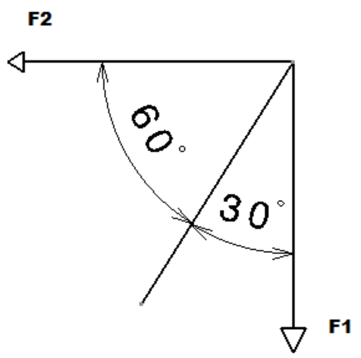


Figure 2.4: External forces over the structure

Where $\boldsymbol{F_2} = 5 \cdot 10^3 \cdot (\cos 60) \cdot 9{,}8 = 24500\ N$ and $\boldsymbol{F_1} = 5 \cdot 10^3 \cdot (1 + \cos 30) \cdot$ *9,8=91435,24 N*

Applying global equilibrium at the structure the reactions in the fixed support can be obtained.

$$\Sigma F_x = 0$$

$$\Sigma F_y = 0 \qquad \textit{(Eq.2.2 a);b);c))}$$

$$\Sigma M = 0$$

$$\boldsymbol{F_{xa}} = 24500\ N;\ \boldsymbol{F_{ya}} = 91435{,}24\ N;\ \boldsymbol{M_a} = 355892{,}5\ Nm$$

Then, dividing the structure in bars and nodes all the internal forces in each element can be calculated by equilibrium.

B1:	B2:	B3:	B4:
$\boldsymbol{N_{x1}} = 0\ N$	$\boldsymbol{N_{x2}} = 91435{,}24\ N$	$\boldsymbol{N_{x3}} = 66935\ N$	$\boldsymbol{N_{x4}} = 129308{,}68N$
$\boldsymbol{V_{y1}} = 66935\ N$	$\boldsymbol{V_{y2}} = 24500\ N$		

$$\boldsymbol{M_{z2}(x)} = x \cdot V_{y2} + M_a$$

$$\boldsymbol{M_{z2}(x=1)} = 380392{,}5\ Nm$$

$$\boldsymbol{M_{z1}(x)} = x \cdot V_{y1}$$

$$\boldsymbol{M_{z1}(x=5)} = 334575\ Nm$$

2.4. Structure diagrams:

After the forces **B1** and **B2** in bars were calculated, the forces diagrams of the pillar can be drawn. Normal force, shear force and bending moment force diagrams were considered.

This diagrams are shown in *Figure 2.5.*

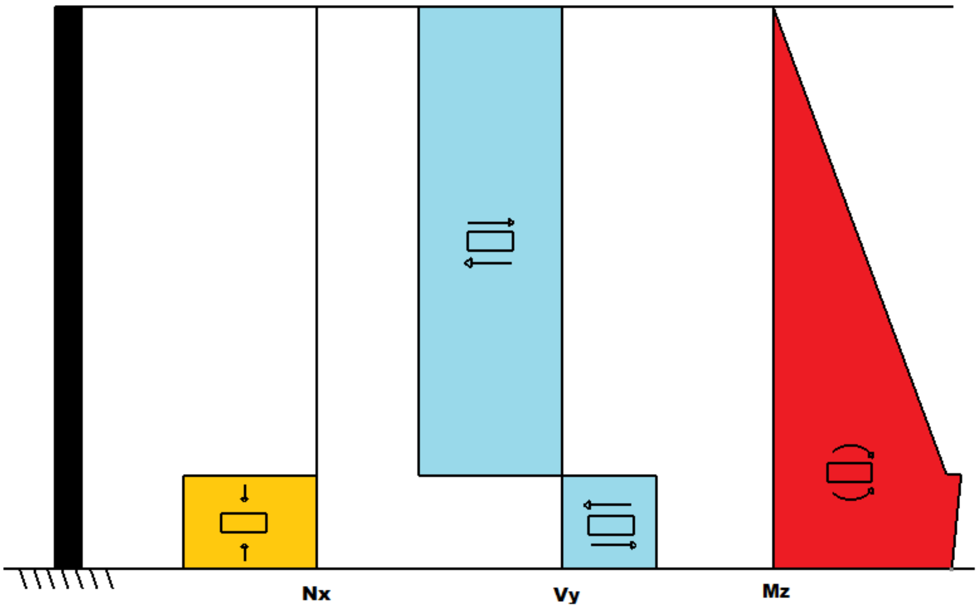


Figure 2.5: Diagrams of forces pillar

To calculate this forces and draw the diagrams can also be easily done using the software. In the following table the results of both methods are presented (hand calculated and software calculated) to be compared .

		N_x	V_y
Bar1	**Theoretical**	$0\ N$	$66935\ N$
	Analysis	$\approx 0\ N$	$66935{,}24N$
Bar 2	**Theoretical**	$91435{,}24\ N$	$24500\ N$
	Analysis	$91435{,}24\ N$	$24500\ N$
Bar 3	**Theoretical**	$66935\ N$	$0\ N$
	Analysis	$66935{,}24\ N$	$0\ N$
Bar 4	**Theoretical**	$129308{,}68N$	$0\ N$
	Analysis	$129308{,}96N$	$0\ N$

Table 2.1: Forces obtained comparison

As it can be seen in the *Table 2.1*, the values of the forces obtained with hand calculations are really close to the values obtained with the software.

It is possible to compare the bending moment in the pillar (B1 and B2 bars) too. The bending moment doesn't have a constant value, therefore the comparison will be between the values in the join of the two bars.

		M_z
Bar1	**Theoretical**	$334575\ Nm$
	Analysis	$334676{,}2\ Nm$
Bar 2	**Theoretical**	$380392{,}5\ Nm$
	Analysis	$380400\ Nm$

Table 2.2: Values of the bending moment in the pillar.

Again the both methods lead to nearly the same values, as it can be observed s in *Table 2.2*. Therefore the check was successful.

2.5. Strain in B3 bar:

The strain in bar B3 can be calculated applying the Hook Law. However, to do so, it is necessary obtain first the stress in B3 bar.

This bar B3 is only under the effect of normal force N_{x3}. The stress will be determinate by the expression *Eq 2.3*:

$$\sigma_{xx} = \frac{N_x}{A} + \frac{M_z}{W_z} \qquad \textbf{\textit{(Eq. 2.3)}}$$

$$\sigma_{xx} = \frac{N_{x3}}{A_3} = \frac{66935N}{314{,}16 \cdot 10^{-6} m^2} = 2{,}13 \cdot 10^8 \, {}^{N}\!/_{m^2}$$

Then, using the Hook Law **σ=ε·E** the strain in the bar will be:

$$\boldsymbol{\varepsilon} = \frac{\sigma}{E} = \frac{N_{x3}}{E \cdot A_3} = \mathbf{1{,}01 \cdot 10^{-3}} \qquad \textbf{\textit{(Eq. 2.4)}}$$

2.6. Stress in B1 and B2 bars:

The pillar (B1 and B2 bars) are under normal force, shear force and bending moment force. Despite the forces are not the same in B1 and B2 bars, it is only necessary reaching the bending moment the highest value. The stress σ_{xx} can be calculated using the *Eq. 2.3* expression:

$$\sigma_{xx1} = \frac{N_{x1}}{A_1} + \frac{M_{z1}}{W_{z1}} = 0 + \frac{M_{z1} \cdot y_{max}}{I_{z1}};$$

$$\sigma_{xx2} = \frac{N_{x2}}{A_2} + \frac{M_{z2}}{W_{z2}} = \frac{N_{x2}}{A_2} + \frac{M_{z1} \cdot y_{max}}{I_{z1}};$$

$$\boldsymbol{\sigma_{xx1}} = 0 + \frac{334575\ Nm \cdot 0{,}3m}{806753139{,}5 \cdot 10^{-12}\ \mathrm{m}^4} = \mathbf{124{,}42 \cdot 10^6}\ {}^{\boldsymbol{N}}\!/_{\boldsymbol{m^2}}$$

$$\boldsymbol{\sigma_{xx2}} = \frac{91435.24\ N}{18535{,}4\ \cdot 10^{-6}\mathrm{m}^2} + \frac{380392{,}5\ Nm \cdot 0{,}3m}{806753139{,}5 \cdot 10^{-12}\ \mathrm{m}^4} = \mathbf{146{,}39 \cdot 10^6}\ {}^{\boldsymbol{N}}\!/_{\boldsymbol{m^2}}$$

Because of the shear force, there are shear stress in bars B1 and B2 that can be obtained knowing the shear force. Nevertheless, it should be noted that as they are thin walled bars, the shear stress will be more important than in solid sections.

To determinate the shear stress it can be used the expression Eq.2.5:

$$\tau_{xy} = \frac{Q \cdot V_y}{I \cdot e} \qquad \textbf{\textit{(Eq.2.5)}}$$

I= Inertia moment

Q = Static moment (first inertia moment)

e = Thickness

Vy = Shear force

Additionally, the maximum value of the shear stress can be calculated using the following expression:

$$\tau_{xy\ max} = \frac{2 \cdot V_y}{A} \qquad \textbf{(Eq.2.6)}$$

$$\tau_{xy1} = \frac{2 \cdot V_{y1}}{A_1} = \frac{2 \cdot 66935N}{18535{,}4 \cdot 10^{-6}\mathrm{m}^2} = 7{,}22 \cdot 10^6\ {}^{N}/_{m^2}$$

$$\tau_{xy2} = \frac{2 \cdot V_{y2}}{A_2} = \frac{2 \cdot 24500N}{18535{,}4 \cdot 10^{-6}\mathrm{m}^2} = 2{,}64 \cdot 10^6\ {}^{N}/_{m^2}$$

2.7. Total stress validation using Von Misses yield criterion:

The Von-Misses yield criterion was used to verify the total stress. The expression considered for the non principal stress is the following:

$$\sigma_{VM} = \sqrt{\sigma_{xx}^2 + 3\tau_{xy}^2} \qquad \textbf{(Eq.2.7)}$$

As there are two different bars (B1 and B2) in the pillar, the validation was carried in both bars. It is possible to know looking at the stress calculated in the point 2.6 that the B2 bar is more critical.

$$\sigma_{VM1} = \sqrt{(124{,}42 \cdot 10^6)^2 + 3(7{,}22 \cdot 10^6)^2} = 125{,}05 \cdot 10^6\ {}^{N}/_{m^2} < 355 \cdot 10^6\ {}^{N}/_{m^2}$$

$$\sigma_{VM2} = \sqrt{(146{,}39 \cdot 10^6)^2 + 3(2{,}64 \cdot 10^6)^2} = 146{,}46 \cdot 10^6\ {}^{N}/_{m^2} < 355 \cdot 10^6\ {}^{N}/_{m^2}$$

The utilisation U can be determined as a coefficient between the yield stress and the Von Misses stress.

$$U_1 = 125{,}05/355 = 0{,}35 < 1$$

$$U_2 = 146{,}46/355 = 0{,}41 < 1$$

Therefore the integrity of the structure is justified.

3. MECHANICAL EQUIPMENT :

This section deals with the dimensioning and calculation of the mechanical equipment required for the crane operation with a capacity of 5 Tonnes and a lifting speed of 10 cm/s.

The rotation speed of the electric motor is n_m=1500 rpm. This speed is reduced by 2%. The motor is attached to a standard gear with D_m= 200mm and Z_m = 20.

The lifting wire is wound on to a drum with a diameter Dt =200mm. The pulleys of the belt transmission have diameters of Dr1=1200mm and Dr2=300mm. And the belt transmission has a lost effect of 6%.

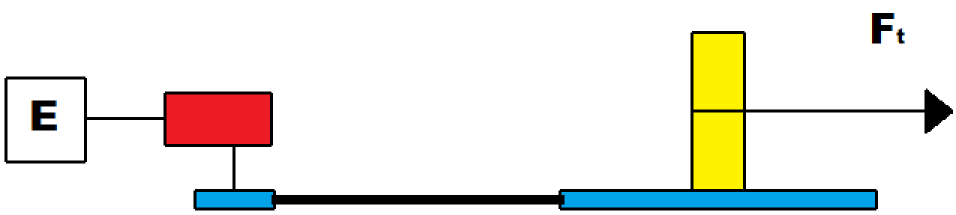


Figure 3.1: Scheme of the mechanism

3.1. Engine power:

The wire produce a force in the drum $\mathbf{F_t}$ = 5000 · 9,8 =49000 N which generates and this force produce a torque what can be determinate applying the expression *Eq.3.1*:

$$\vec{T} = \vec{r} x \vec{F} \qquad \textbf{(Eq.3.1)}$$

In this case, only the module is concern therefore it is possible to use a dot product.

$\mathbf{T_t = F_t \cdot r_t}$=49000·0,1=**4900 Nm.**

The lifting speed is $\mathbf{V_t}$=10 cm/s **= 0,1 m/s**. Consequently the power of the lifting wire was calculated according to the equation *Eq.3.2:*

$$P = v \cdot F \qquad \textbf{(Eq.3.2)}$$

$\mathbf{P_t}$ = $V_t \cdot F_t$ = 0,1·49000=4900 W = **4,9 kW**

The power of the engine must be the same of the power demanded in the wire:

$\mathbf{P_E}$ = P_t= **4,9 kW**

3.2. Wire-drum speed (n_t):

It is easy to determine the wire-drum speed from the power or lifting speed using one of the *Eq. 3.3* or *Eq.3.4* expressions:

$$P = T \cdot \omega \qquad \textbf{(Eq.3.3)}$$

$$v = r \cdot \omega \qquad \textbf{(Eq.3.4)}$$

$$\boldsymbol{n_t} = \frac{v}{r} = \frac{P}{T} = 1\,{}^{rad}/_{s} = \mathbf{9,54}\ \boldsymbol{rpm}$$

3.3. Speed of the pulleys:

The speed of the pulley which is connected to the wire-drum, the large pulley, will be the same speed of the wire-drum. Therefore the speed of the large pulley is:

$$\boldsymbol{n_1} = n_t = \mathbf{9,54}\ \boldsymbol{rpm}$$

The transmission ratio between the two pulleys can be expressed according to the equation *Eq.3.5*:

$$R_1 = \frac{n_2}{n_1} = \frac{Dr_1}{Dr_2} \qquad \textbf{(Eq.3.5)}$$

$$R_1 = \frac{1200}{300} = 4$$

$$\boldsymbol{n_2} = n_1 \cdot R_1 = 9{,}54 \cdot 4 = 38{,}16\ rpm$$

However it is necessary to correct this value because of the fact that the belt transmission has a lost effect of 6%.

$$\boldsymbol{n_{2'}} = \frac{n_2}{0{,}94} = \mathbf{40,6}\ \boldsymbol{rpm}$$

3.4. Gear ratio between engine and small pulley:

The gear ratio between the engine and the small pulley can be obtained using the expression *Eq.3.5*:

$$\boldsymbol{R_2} = \frac{Dr_2}{Dm} = \frac{300mm}{200mm} = \mathbf{1,5}$$

3.5. Incoming speed on the gear box:

Knowing that the speed of the engine is reduced by 2%, the real speed will be:

$$\boldsymbol{n_{m'}} = n_m \cdot 0{,}98 = 1500 \cdot 0{,}98 = \mathbf{1470}\ \boldsymbol{rpm}$$

Therefore this speed $n_{m'}$ is the incoming speed in the gearbox and the outgoing speed will be $n_{2'}$, then the gearbox must reduce the speed from the incoming speed to the outgoing speed.

3.6. Speed ratio in the gear box:

The speed ratio will be the relation between these two speeds:

$$\boldsymbol{R_2} = \frac{n_{m'}}{n_{2}'} = \frac{1470}{40{,}6} = \mathbf{36{,}20}$$

3.7.Dimension the incoming gear:

The two engage sprockets should have the same modulus*,* ***m***, and the same pitch, ***p***. Both, the modulus and the pitch are related by the expression *Eq.3.6:*

$$m = \frac{p}{\pi} = \frac{d}{Z} \qquad \textbf{(Eq.3.6)}$$

The gear connected to the engine has a number of teeth Z_m = 20 and a diameter D_m= 200mm.

Then, according to the equation *Eq.3.6,* the modulus will be:

$$\boldsymbol{m} = \frac{200}{20} = \mathbf{10}$$

Consequently, the incoming gear of the gear box should have the same modulus ***m=10,*** thus, the diameter must be ten times the number of teeth.

3.8. The engine speed when the effect is reduced by the system

The effect is reduced by the system by 37%, which means that the 37% of the power produced by the engine is lost in the way to the wire-drum.
The lifting speed in the wire-drum must be the same and therefore the power as well.

The engine has to produce 37% additional power than the demanded in the wire to meet the needs:

$$\mathbf{P_{E'}} = =4900\ \text{W} / 0{,}63 = \mathbf{7{,}77\ kW}$$

The new engine speed is determined by the expression Eq.3.3 and considering it is reduced by 2%:

$$\boldsymbol{n_{m''}} = \frac{n_m}{0{,}63} = (1500 \cdot 0{,}98)/0{,}63 = \mathbf{2333{,}33\ rpm}$$

4. CONCLUSIONS

Regarding to the first part of the report, the structural calculus of the crane, and looking at the forces, the most stressed bars are B3 and the pillar (B1 and B2 bars). In addition, the most critical section within the pillar is the join between B1 and B2 bars. However, the integrity of the structure has been justified by calculating the maximum stress in this section and applying the Von Misses. Therefore, it is possible to built this crane to be used in the conditions described. Nevertheless, it would be necessary more calculations such as stress concentrations in some parts or a buckling study to ensure the suitability of the crane in the described conditions.

According to the second part of the report, the mechanical equipment design, it is possible to built this equipment assuming the energy lost in the belt transmission, and noticing that the gearbox must have an incoming gear with a determinate modulus. The incoming speed is approximately 36 times the value of the outgoing. In the case of the energy wasted, it will be necessary increase the engine speed in order to produce more power and keep then the lifting speed within the proper range of values. The gear box would have to be modified in that case.

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ATTACHED:

I. Software calculated forces in the crane:

Bar 1		**0,00**	**0,62**	**1,25**	**1,88**	**2,5**	**3,12**	**3,75**	**4,38**	**5,00**
	Nx	86,58E-04	86,58E-04	86,58E-04	86,58E-04	86,58E-04	86,58E-04	86,58E-04	86,58E-04	86,58E-04
	Vy	6,69E04	6,69E04	6,69E04	6,69E04	6,69E04	6,69E04	6,69E04	6,69E04	6,69E04
	Mz	43,29E-04	4,183E04	8,367E04	12,55E04	16,73E04	20,92E04	25,1E04	29,28E04	33,47E04
Bar 2		**0,00**	**0,12**	**0,25**	**0,38**	**0,50**	**0,62**	**0,75**	**0,88**	**1,00**
	Nx	9,144E04	9,144E04	9,144E04	9,144E04	9,144E04	9,144E04	9,144E04	9,144E04	9,144E04
	Vy	2,45E04	2,45E04	2,45E04	2,45E04	2,45E04	2,45E04	2,45E04	2,45E04	2,45E04
	Mz	38,04E04	37,73E04	37,43E04	37,12E04	36,81E04	36,81E04	36,2E04	35,9E04	35,54E04
Bar 3		**0,00**	**0,62**	**1,25**	**1,88**	**2,50**	**3,12**	**3,75**	**4,38**	**5,00**
	Nx	6,694E04	6,694E04	6,694E04	6,694E04	6,694E04	6,694E04	6,694E04	6,694E04	6,694E04
	Vy	-	-	-	-	-	-	-	-	-
	Mz	-	-	-	-	-	-	-	-	-
Bar 4		**0,00**	**0,88**	**1,77**	**2,65**	**3,54**	**4,42**	**5,30**	**6,19**	**7,07**
	Nx	12,93E04	12,93E04	12,93E04	12,93E04	12,93E04	12,93E04	12,93E04	12,93E04	12,93E04
	Vy	-	-	-	-	-	-	-	-	-
	Mz	-	-	-	-	-	-	-	-	-