National University of San Agustín
Faculty of Production and Services
School of Mechanical Engineering

Design of a 350 TPH Copper Concentrate Feed Conveyor Belt with Electro-Hydraulic Tensioning Automation and Receiving Hopper

Thesis to qualify for the title of **MECHANICAL ENGINEER**, presented by the bachelor:

CAIPO CCOA MANUEL ALBERTO

ADVISOR: M.Sc. Adriazola

1 GENERAL APPROACH

1.1 Problem Statement

This document aims to detail the design procedure for an oleo-hydraulic tensioning system in conveyor belts for general application. While standards such as CEMA (Conveyor Equipment Manufacturers Association), CEMA B105.1 (Welded Steel Conveyor Pulleys), and ANSI/AISC 360-10 (American Institute of Steel Construction) provide design methodologies and criteria, none of these specifically offer technical design specifications for oleo-hydraulic tensioning automation. Additionally, the design procedure for conveyor belt components will be detailed, outlining design procedures, tension calculations, accessory selection, and methods for defining the geometric path of the belt for optimal operation.

1.2 Research Objective

1.2.1 General Objective

To design a 350 ton/h copper concentrate feed conveyor belt with oleo-hydraulic tensioning automation, utilizing finite element mechanical structural analysis of the conveyor components and receiving hopper, in contrast with design standards CEMA, CEMA B105.1, and ANSI/AISC 360-10

1.2.2 Specific Objectives

I. Analyze input data for the feeding system.
II. Outline design methodologies by discipline in mechanical structural design.
III. Detail the definition and evaluation of dynamic loads on the receiving hopper due to material flow using a conservative criterion.
IV. Perform mechanical structural design calculations for the entire material feeding system (copper concentrate) based on relevant standards (regulations).
V. Geometrically define material conveying on the conveyor belt and the skirt geometry for conveying, ensuring proper transport of copper concentrate.
VI. Determine stress criteria involved in the finite element design of tail and drive pulleys.
VII. Select idlers, cleaners, bearings, and pillow blocks for the feed conveyor belt.
VIII. Define the oleo-hydraulic tensioning scheme for vertical and horizontal applications in conveyor belts.
IX. Prepare detailed engineering drawings.

1.3 Variables

1.3.1 Independent Variables

- Flow rate of copper concentrate to be transported.
- Design loads based on location.
- Seismic zone of the site.

1.3.2 Dependent Variable

- Analysis and definition of factors involved in the design of a 350 ton/h copper concentrate feed conveyor belt with oleo-hydraulic tensioning automation and a receiving hopper.

1.4 Justification and Importance

1.4.1 Justification

- **Addresses Limitations:** Conventional manual tensioning is time-consuming and poses occupational health risks.
- **Proposes Solution:** Develops a detailed, generalizable oleo-hydraulic tensioning system to improve efficiency and safety.
- **Enhances Design:** Combines standard design methodologies with Finite Element Analysis (FEA) for robust structural design.

1.4.2 Importance

- **Safety & Efficiency:** Safeguards personnel and ensures efficient conveyor operation, increasing availability and reducing downtime.
- **Advanced Control:** Provides automatic tension control, eliminating manual adjustments and offering precise tension logging for predictive maintenance.
- **Reduced Downtime:** Significantly speeds up belt replacement by eliminating manual counterweight handling, minimizing production halts.
- **Versatile Application:** While horizontal, the system can replace counterweight tensioners with advantages in control, data, and maintenance speed.

1.4 Type of Research

The presented research is applied, explanatory, and non-experimental.

2. REFERENCE FRAMEWORK

2.1 Theoretical Framework

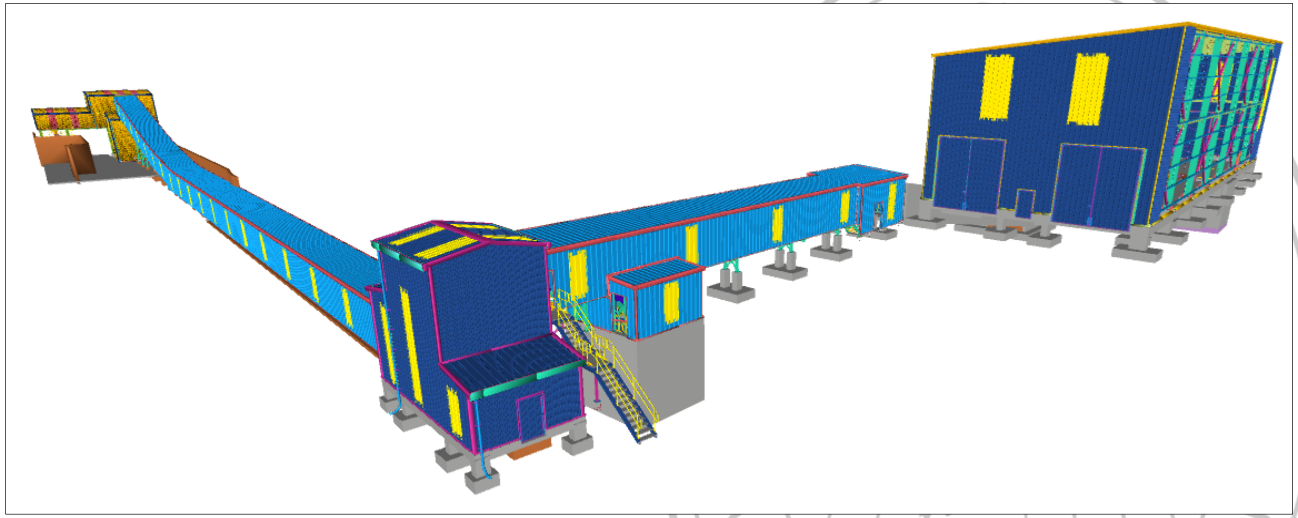
- Conveyor Belts
- Conveyor Belt Components
- Belt Tensioning
- Feeders
- Gears
- Hydraulics
- Oleo-hydraulics
- Structural Analysis
- Failure Criteria
- Finite Element Analysis (ANSYS/IDEA Statica/SAP 2000)

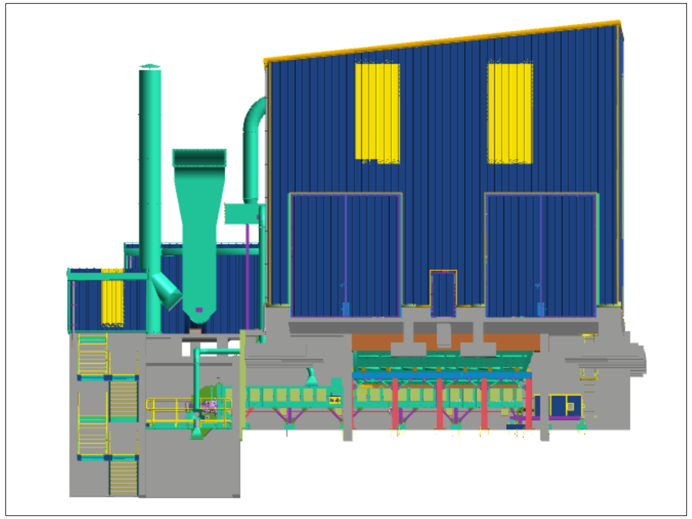
2.1 Hypothesis Statement

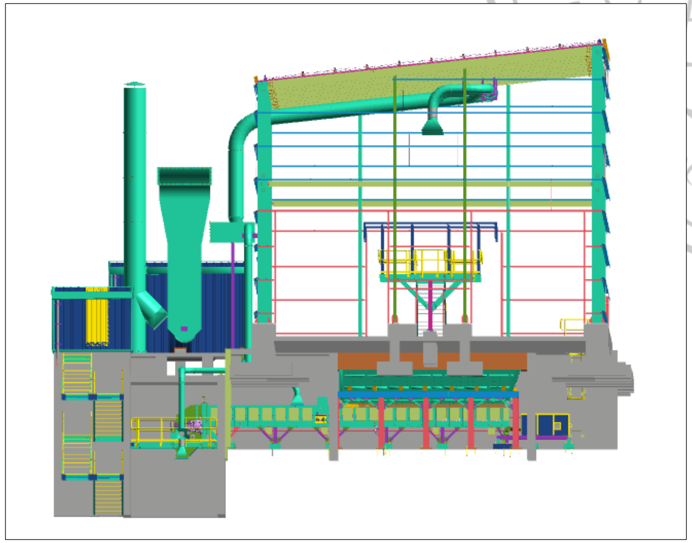
The mechanical structural design of conveyor belt components, adhering to design standards, is conservative and possesses an appropriate safety factor for the proper operation of the belt. This can be validated through finite element analysis. Furthermore, the design of an oleo-hydraulic schematic for automatic tensioning in a flat feed conveyor can be generalized as a tensioning solution for any other contingency.

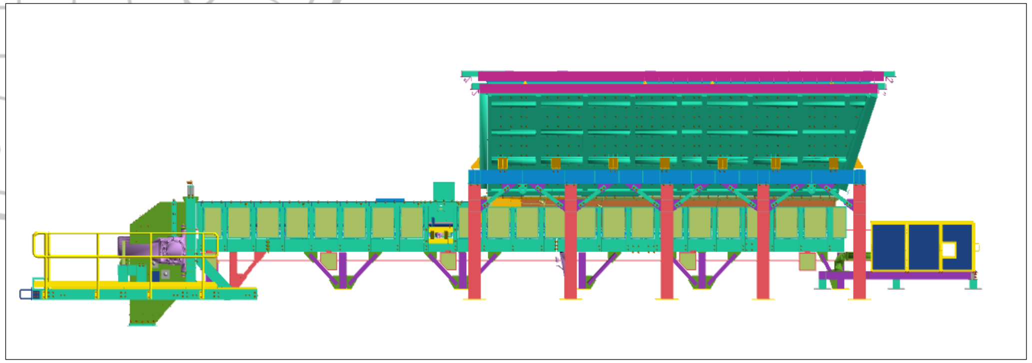
3. Calculation Report for the Feeding System

3.1 Description of the Situation: Feeding Conveyor Belt in the Copper Concentrate Transportation Process (Feeder) 350 TN/H



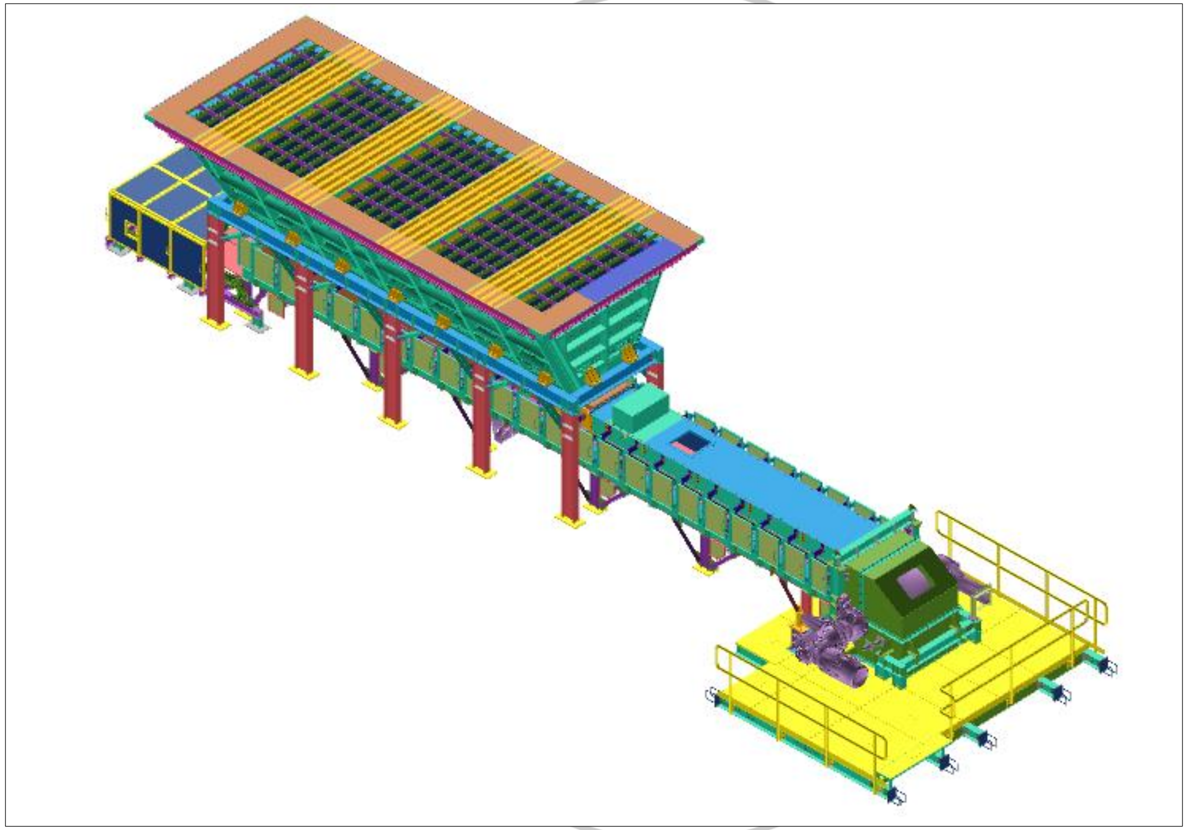






3. Calculation Report for the Feeding System

3.1 Description of the Situation: Feeding Conveyor Belt in the Copper Concentrate Transportation Process (Feeder) 350 TN/H



Isometric View of the Feeding Conveyor Belt and Receiving Hopper
Source: Own Work

3.2 Design Methodology

The analysis for the mechanical and structural design of the conveyor belt and material receiving hopper is carried out based on the following table:

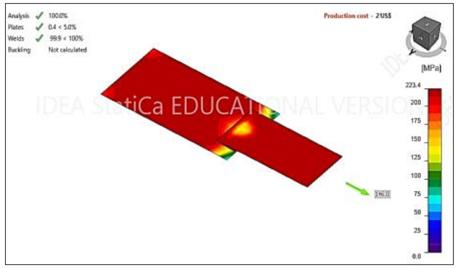
Design Methodologies According to Discipline				
Discipline	Component	Activity / Criterion	Standard / Code	Reference Description
Structural Design	Conveyor Belt	Load Definition	ASCE 7-16	Minimum Design Loads and Associated Criteria for Buildings and Other Structures
		Load Combination	ASCE 7-16	Minimum Design Loads and Associated Criteria for Buildings and Other Structures
		Structural Analysis	NTP E.030 2018	Technical Standard for Seismic-Resistant Design
		Connection Analysis	AISC 360-16/10	American Institute of Steel Construction
	Receiving Hopper	Load Definition	Eurocode 1 Part 4	Actions in Silos and Storage Tanks
		Load Combination	ASCE 7-16	Minimum Design Loads and Associated Criteria for Buildings and Other Structures
		Structural Analysis	NTP E.030 2018	Technical Standard for Seismic-Resistant Design
		Connection Analysis	AISC 360-16/10	American Institute of Steel Construction
Mechanical Design	Conveyor Belt	Stress Definition	CEMA 6th	Conveyor Equipment Manufacturers Association
		Power Calculation	CEMA 6th	Conveyor Equipment Manufacturers Association
		Tensioner Calculation	CEMA 6th	Conveyor Equipment Manufacturers Association
	Pulleys	Load Assignment	Finite Element Analysis	Welded Steel Conveyor Pulleys
		Stress Analysis	Finite Element Analysis	Welded Steel Conveyor Pulleys
	Hydraulic Tensioner	Tensioning Load	CEMA 6th	Conveyor Equipment Manufacturers Association

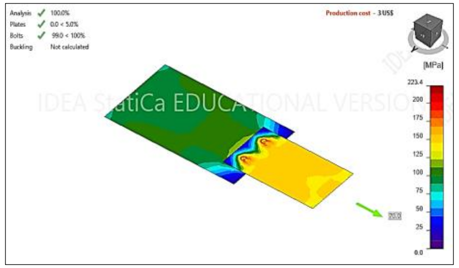
3.3 Evaluation Using Software

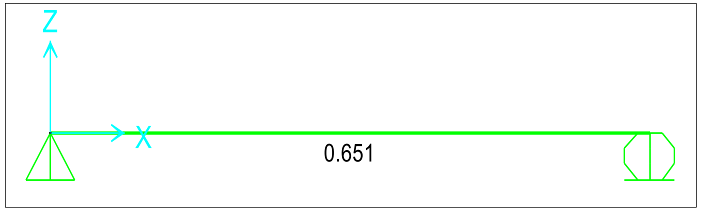
The analysis for the mechanical and structural design of the conveyor belt and the material receiving hopper is carried out based on the following table:

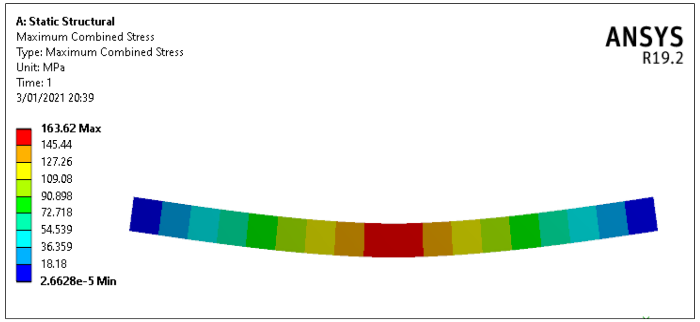
Structural and Connection Analysis

Section	Item	Description	Methodology	Ratio	Deformation (mm)	Percentage Variation of Ratio	Percentage Variation of Deformation
Structural Analysis	1	Beam Analysis	Analytical Method	0.651	8.5	0.00%	0.00%
			SAP2000 Software	0.651	9.1	0.00%	7.10%
			ANSYS Software	0.654	9.46	0.50%	11.30%
	2	Column Analysis	Analytical Method	0.509	1.92	0.00%	0.00%
			SAP2000 Software	0.488	1.92	4.10%	0.00%
Connection Analysis	1	Welded Connection Analysis	Analytical Method	0.9921	-	0.00%	-
			Idea Statica Software	0.999	-	0.70%	-
	2	Bolted Connection Analysis	Analytical Method	0.987	-	0.00%	-
			Idea Statica Software	0.99	-	0.30%	-



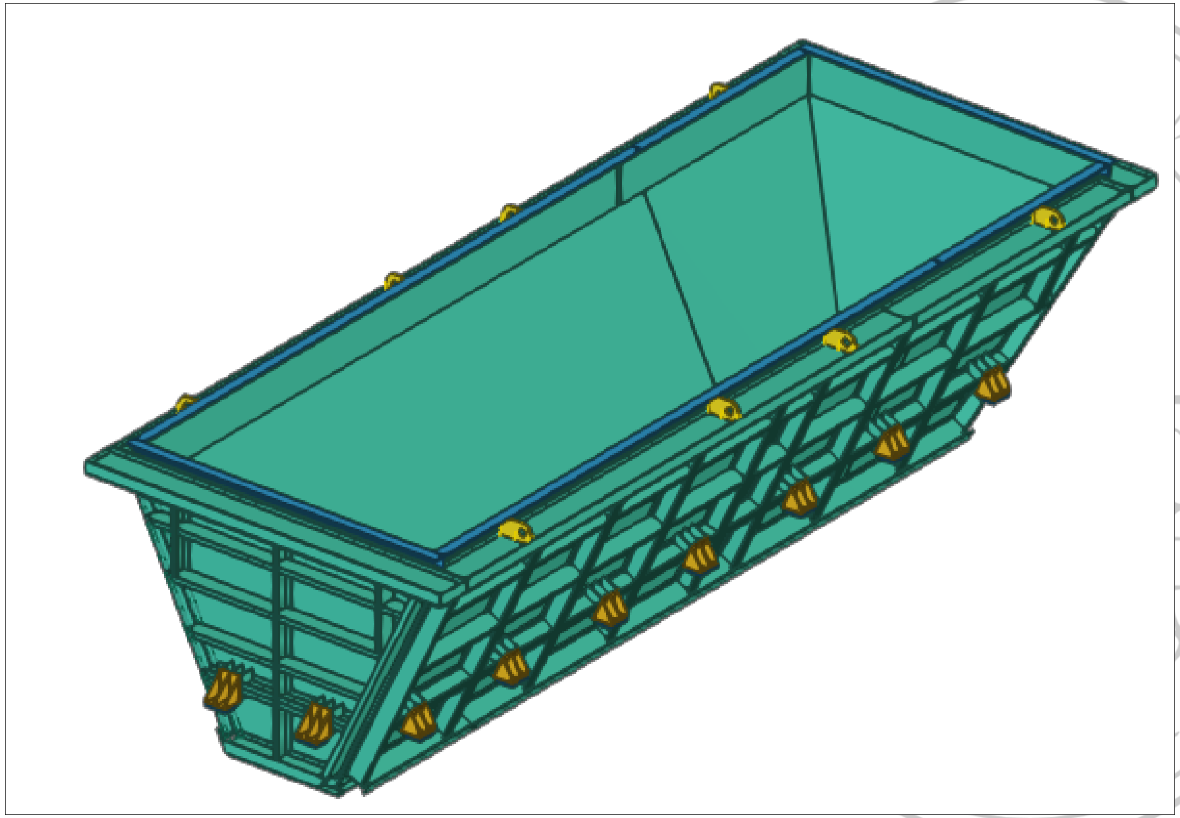






3.4 Mechanical Calculation of the Receiving Hopper

The analysis for the mechanical and structural design of the conveyor belt and the material receiving hopper is carried out based on the following table:



$$Q_n: 350\,\frac{ton}{h}$$

$$V: 28.2\ m^3$$

V: Internal Material Volume of the Receiving Hopper

$$\rho: 1950\,\frac{kg}{m^3} = 122\,\frac{lb}{ft^3}$$

$$M: V\ \rho = 60.56\ ton = 54.94\ tonne$$

$$1\ ton = 2000\ lb$$

$$1\ tonne = 1000\ kg$$

M: Mass Capacity of the Receiving Hopper.

$$n: \frac{Q_n}{M} = 5.78\ \frac{1}{hr}$$

n: Minimum Number of Feedings to Maintain a Flow of 350 t/h

$$\frac{1}{n}: 10.38\ min$$

$\frac{1}{n}$: Interval in Minutes for Material Filling to Sustain the Flow.

3.5 Mechanical Calculation of the Conveyor Belt

In this section, we will examine the design of the conveyor belt (belt width, tension calculation, and power), drive pulley, tail pulley, and gear gate.

3.5.1 Standards and Codes Related to the Mechanical Design of the Conveyor Belt

CEMA	Belt conveyor for bulk materials/Conveyor equipment manufacturers association	6th Edition
DIN 22101	Belt conveyors for loose bulk materials	

Input Data for the Mechanical Design of Conveyor Belt			
1.0	**Main Function**		Feeding to conveyor lines
2.0	**Site Conditions**		
	Project Location	—	Islay/Arequipa
	Elevation	masl	6 / 54
	Operating Temperature (Min/Max)	°C	+15 / +27
	Relative Humidity (Min/Max)	%	55 / 82
	Precipitation: Maximum (Annual)	mm	7
	Wind Speed (Min/Max)	km/h	9.5 / 13.1
	Seismic Zone according to RNE E.030	—	Zone 4
3.0	**General Data**		
	Number of Units	unit	1
	TAG No.	—	150-FE-001
	Belt Feeder Width	in.	42"
	Distance Between Pulley Centers	m	15.45
	Slope	°	0

4.0	Process Data	Unit	Nominal Value
	Material to be transported	—	Copper concentrate
	Bulk density of the ore	kg/m³ (lb/ft³)	1950 (122)
	Ore size	mesh	< 50
	Capacity (nominal / maximum)	t/h	350
	Mass flow (solids)	t/h	325.5
	Moisture	%	9
	Angle of repose	°	37
	Internal friction increase factor	—	1.9
	Internal friction angle	°	35
	surcharge angle	°	25
	Friction factor between material and skirts	—	0.2
	Load percentage	%	100
	Particle size distribution	%	100% fines
	CEMA material classification	—	A36
	Start-up type	—	Soft start
	Working hours	h	24
	Days per week	d	7
	Days per year	d	365
	Equipment availability	%	90
	Nominal power / motor (effective @ 54 masl)	hp	60
	Belt speed	m/s	0.37
	Start-up factor	—	1.2
	Pulley wrap angle	°	180
	Belt–drive pulley friction coefficient in operation	—	0.3
	Belt–drive pulley friction coefficient at start/stop	—	0.35
	Percentage reduction of friction due to humid environment	%	20

3.5.2 Belt Width Calculation

$$v: 0.75\frac{m}{s} = 147.6\ \frac{ft}{min}$$

$$Q_d: Q_n\frac{FD}{\gamma} = 5737.7\frac{ft^3}{hr}$$

$$Q_{100}: Q_d\frac{100\frac{ft}{min}}{v} = 3886.3\frac{ft^3}{hr}$$

Table 4.7
Flat belt, standard edge distance

Belt Width (in)	A_{sc} Cross Sectional Area (ft²) Surcharge Angle (deg)							Capacity (ft³/hr) at 100 fpm Surcharge Angle (deg)						
	0	5	10	15	20	25	30	0	5	10	15	20	25	30
18	NA	0.020	0.041	0.062	0.083	0.105	0.127	NA	123	246	371	498	629	763
24	NA	0.039	0.078	0.117	0.157	0.198	0.241	NA	232	466	702	943	1,190	1,444
30	NA	0.063	0.126	0.190	0.255	0.321	0.390	NA	376	755	1,138	1,528	1,928	2,340
36	NA	0.092	0.185	0.280	0.376	0.474	0.575	NA	555	1,113	1,678	2,253	2,843	3,452
42	NA	0.128	0.257	0.387	0.520	0.656	0.796	NA	768	1,541	2,323	3,119	3,936	4,778
48	NA	0.169	0.340	0.512	0.688	0.868	1.053	NA	1,016	2,038	3,072	4,126	5,206	6,320
54	NA	0.216	0.434	0.654	0.879	1.109	1.346	NA	1,298	2,604	3,927	5,273	6,654	8,077
60	NA	0.269	0.540	0.814	1.093	1.380	1.675	NA	1,615	3,240	4,885	6,561	8,278	10,050
72	NA	0.392	0.787	1.186	1.593	2.010	2.440	NA	2,353	4,720	7,117	9,558	12,060	14,640
84	NA	0.538	1.080	1.628	2.186	2.758	3.349	NA	3,229	6,478	9,767	13,117	16,551	20,092
96	NA	0.663	1.330	2.005	2.693	3.397	4.124	NA	3,977	7,979	12,029	16,155	20,384	24,746
108	NA	0.899	1.804	2.721	3.654	4.610	5.596	NA	5,397	10,827	16,323	21,922	27,660	33,578
120	NA	1.115	2.236	3.371	4.528	5.713	6.935	NA	6,688	13,417	20,229	27,167	34,278	41,613

Table 4.2
Recommended maximum belt speeds

Material Being Conveyed	Belt Speeds (fpm)	Belt Width (in)
Grain or other free flowing, nonabrasive material	400 600 800 1000 1200	18 24-30 36-42 48-96 108-120
Coal, damp clay, soft ores, overburden and earth, fine crushed stone	600 800 1000 1200 1400	18 24-36 42-60 72-96 108-120
Heavy, hard, sharp edged ore, coarse crushed stone	400 600 800 1000 1200	18 24-36 42-60 72-96 108-120
Foundry sand, prepared or damp; shake-out sand with small cores, with or without small castings (not hot enough to harm belting)	350	Any Width
Prepared foundry sand and similar damp (or dry abrasive) materials discharged from belt by rubber edged plows	200	Any Width
Nonabrasive materials discharged from belt by means of plows	200 Except for wood pulp where 300 to 400 is preferable	Any Width
Feeder belts, flat or troughed, for feeding fine, nonabrasive, or mildly abrasive materials from hoppers and bins	50 to 100	Any Width

$$Q_{100t}: 3936\ \frac{ft^3}{hr}$$

$$\frac{Q_{100}}{Q_{100t}}: 0.987 = 98.7\%$$

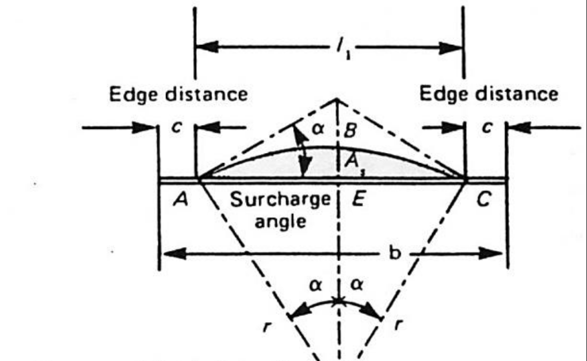


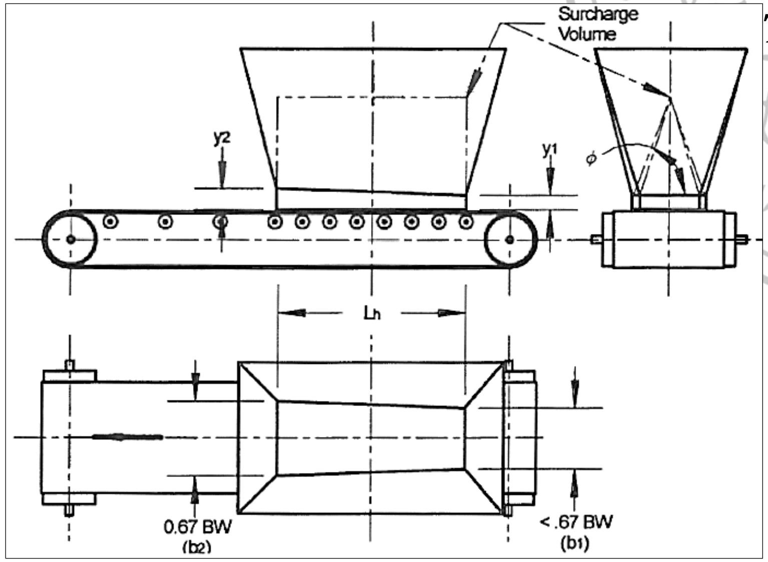
Diagram of flat belt loading

3.5.3 Selection of Idlers

Table 5.1
CEMA idler classification

Classification	Roll Diameter (in)	Belt Width (in)
B4	4	18 through 48
B5	5	18 through 48
C4	4	18 through 60
C5	5	18 through 60
C6	6	24 through 60
D5	5	24 through 72
D6	6	24 through 72
E6	6	36 through 96
E7	7	36 through 96
F6	6	60 through 96
F7	7	60 through 96
F8	8	60 through 96

3.5.4 Tension and Effective Power Calculation



$$T_{e-feeder}: T_q + T_s + [W_m H + 0.04(W_b + W_m)L] + T_{acc} = 89.43KN$$

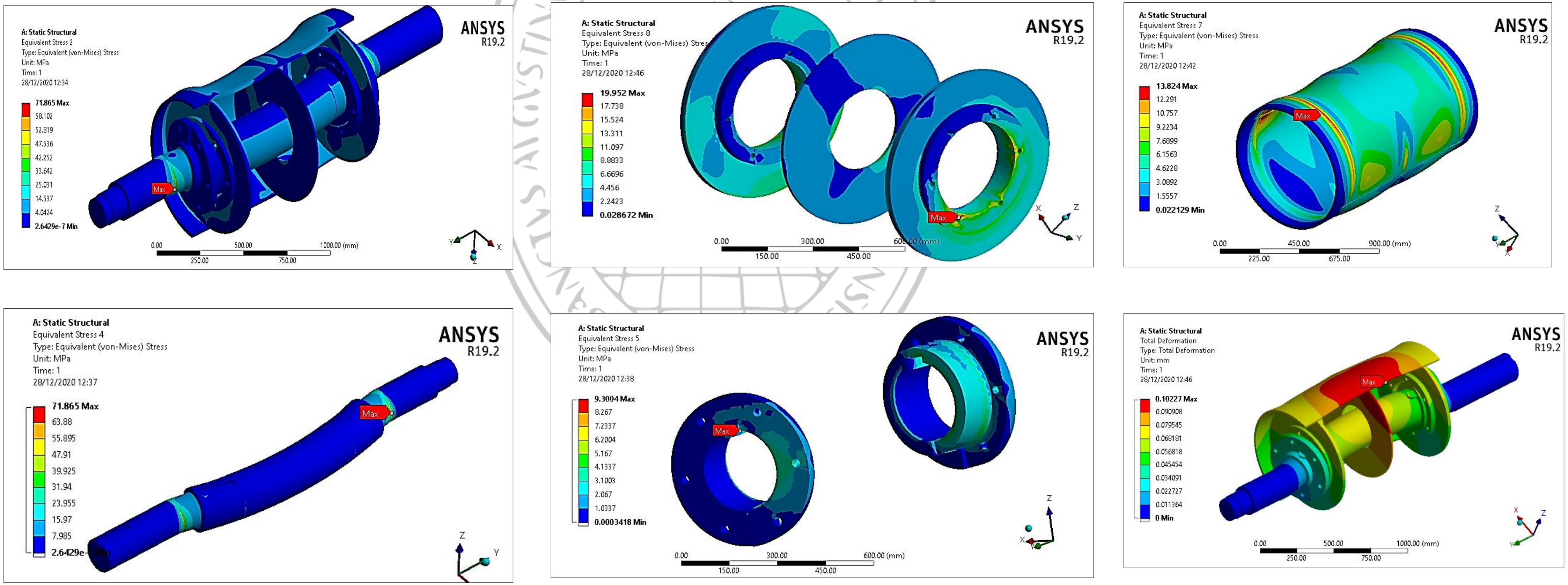
Summary of Results in Mechanical Calculation			
Item	**Description**	**Value**	**Units**
1	Tension on loaded side at start-up	183.4	kN
2	Tension on slack side at start-up	76.1	kN
3	Tension on loaded side in operation	165.5	kN
4	Tension on slack side in operation	63.4	kN
5	Conveyor belt power	53.3	hp
6	Transport speed	0.4	m/s

3.5.5 Pulley Calculation

$$PIW_1 : \frac{T_1}{b} = 981.79\,\frac{Lbf}{in} = 171.94\ \frac{kN}{m}$$

$$PIW_2 : \frac{T_2}{b} = 407.37\,\frac{Lbf}{in} = 71.34\ \frac{kN}{m}$$

Drive Pulley



Drive Pulley

Item	Component	S_y	S_u	S_n (Estimated Fatigue Strength – ksi)						σ_{VM}		FS_{Sy}	FS_{Sn}
		ksi(Mpa)	ksi(Mpa)	$S_{n'}$	C_m	C_{ts}	C_r	C_s	S_n	Mpa	ksi	-	-
01	Shaft	60(655)	95(414)	38.0	0.8	1.0	0.9	0.7	19.2	71.9	10.3	9.1	1.9
02	Compression Hub	55(379)	90(620)	34.0	0.8	1.0	0.5	1.0	13.6	9.3	1.3	40.8	10.2
03	Key	55(379)	90(620)	34.0	0.8	0.8	0.5	1.0	10.9	9.3	1.3	40.8	8.1
04	Hub welded to Disc	36(250)	58(400)	22.0	0.8	1.0	0.9	1.0	15.8	20.0	2.9	12.5	5.5
05	Disc	36(250)	58(400)	22.0	0.8	1.0	0.9	1.0	15.8	16.5	2.4	15.2	6.7
06	Drum	36(250)	58(400)	22.0	0.8	1.0	0.9	1.0	15.8	13.8	2.0	18.1	8.0

$S_{n'}$: Modified fatigue strength in ksi – Source: (Mott, 2006)

C_m: Material factor – Source: (Mott, 2006)

C_{ts}: Type of stress factor $C_{ts}: 1$ para for bending stress $C_{ts}: 0.8$ for axial tension – Source: (Mott, 2006)

C_r: Reliability factor $C_r: 0.9$ for 90% reliability $C_r: 0.5$ 0.5 for 100% reliability - Source : (Mott, 2006)

C_s: Size factor $C_r: 0.7$ for shaft diameter 50mm<D<250mm – Source: (Mott, 2006)

σ_{VM}: Von Mises stress

FS_{Sy}: Safety factor in yielding

FS_{Sy}: Safety factor in fatigue

Item	Component	Material	S_y	S_u
			ksi(Mpa)	ksi(Mpa)
01	Shaft	SAE 4140 HR	60(655)	95(414)
02	Compression Hub	SAE 1045	55(379)	90(620)
03	Key	SAE 1045	55(379)	90(620)
04	Hub welded to Disc	ASTM A36	36(250)	58(400)
05	Disc	ASTM A36	36(250)	58(400)
06	Drum	ASTM A36	36(250)	58(400)

Driving Pulley Vibration Assessment:

$$w_{r1}: 0.97\ \frac{rad}{s}$$

w_{r1}: Angular velocity of the driving pulley

$$T_{rm}: \frac{2\pi}{w_{r1}} = 6.46\ s$$

$$f_{rm}: \frac{1}{T_{rm}} = 0.15\ Hz$$

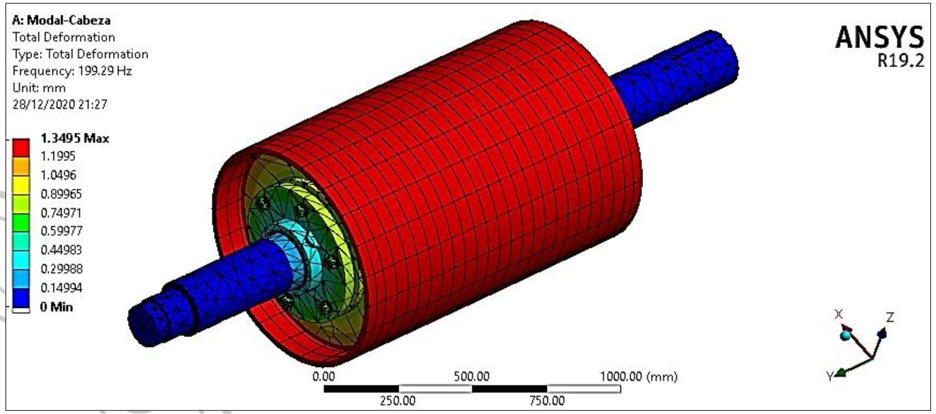
T_{rm}: Operating period of the driving pulley system

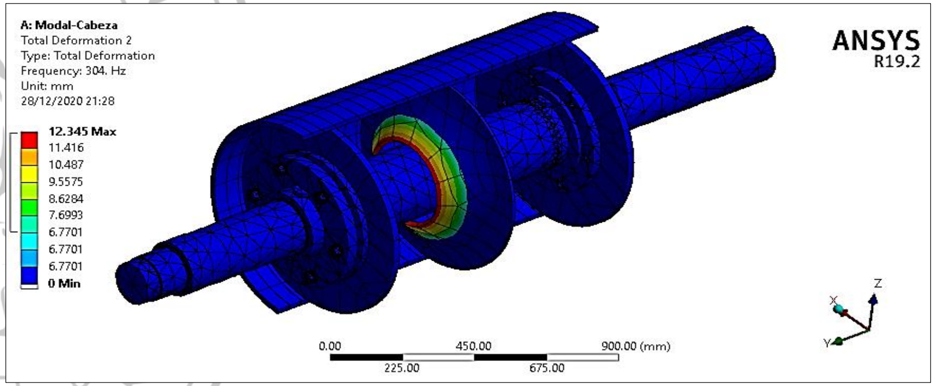
f_{rm}: Operating frequency of the driving pulley system

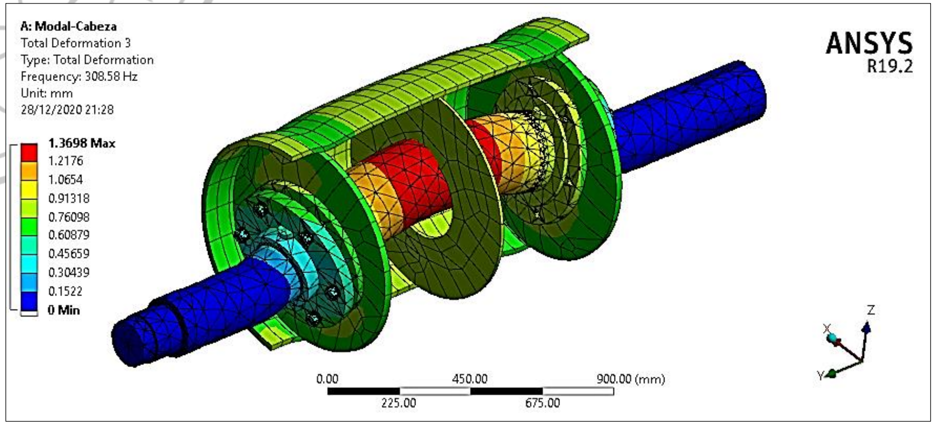
$$f_{rn}: 199.29\ Hz$$

f_{rn}: Natural frequency of the driving pulley system in the first vibration mode

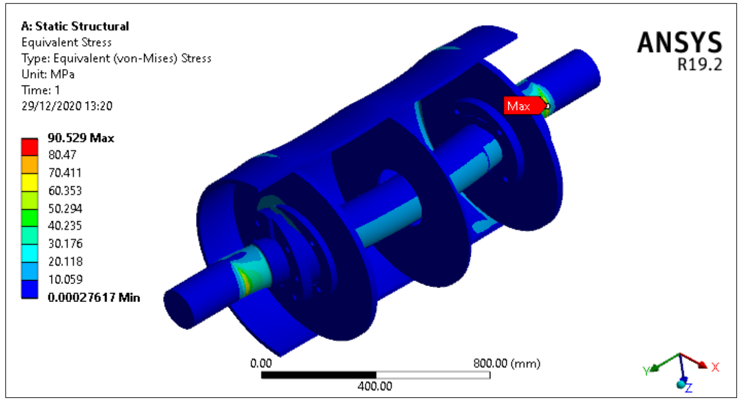
$$f_{rn} \gg f_{rm}\ (ok)$$

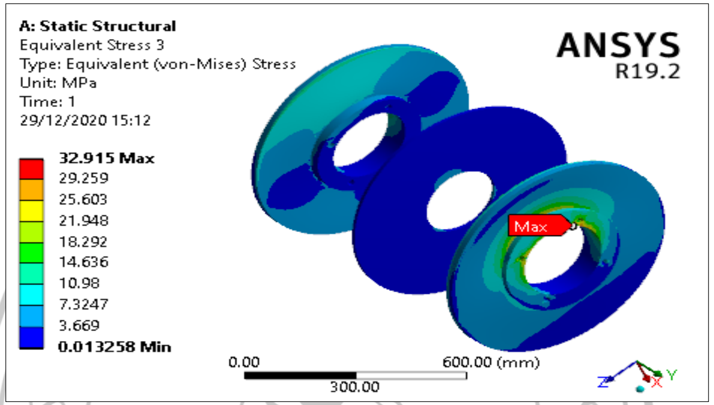


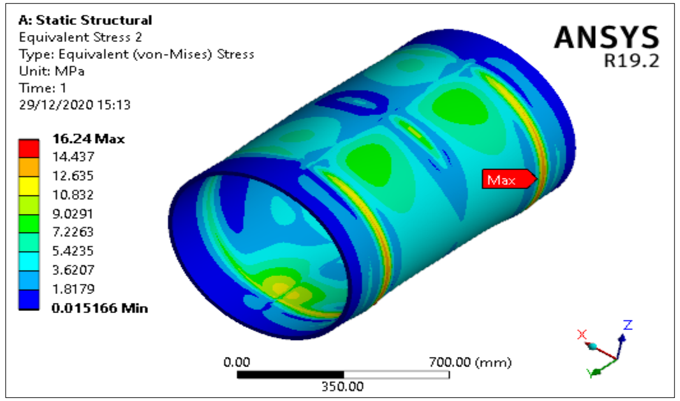


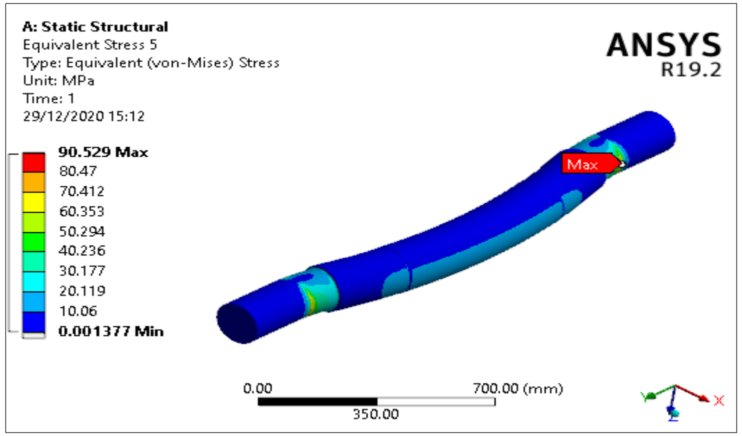


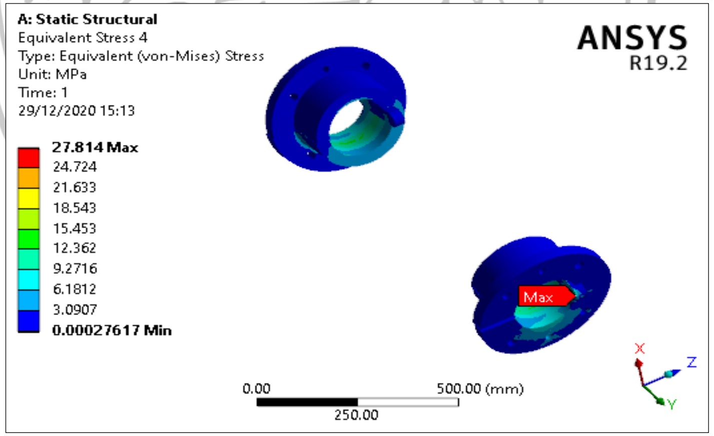
Tail pulley

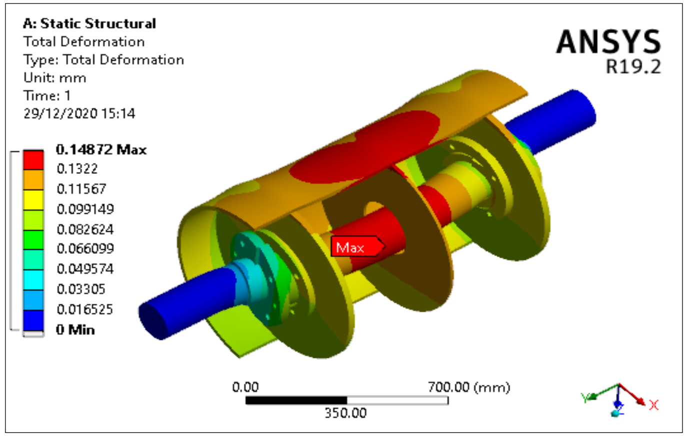

A: Static Structural
Equivalent Stress
Type: Equivalent (von-Mises) Stress
Unit: MPa
Time: 1
29/12/2020 13:20
90.529 Max
80.47
70.411
60.353
50.294
40.235
30.176
20.118
10.059
0.00027617 Min
ANSYS
R19.2
Max
0.00
800.00 (mm)
400.00


A: Static Structural
Equivalent Stress 3
Type: Equivalent (von-Mises) Stress
Unit: MPa
Time: 1
29/12/2020 15:12
32.915 Max
29.259
25.603
21.948
18.292
14.636
10.98
7.3247
3.669
0.013258 Min
ANSYS
R19.2
Max
0.00
600.00 (mm)
300.00


A: Static Structural
Equivalent Stress 2
Type: Equivalent (von-Mises) Stress
Unit: MPa
Time: 1
29/12/2020 15:13
16.24 Max
14.437
12.635
10.832
9.0291
7.2263
5.4235
3.6207
1.8179
0.015166 Min
ANSYS
R19.2
Max
0.00
700.00 (mm)
350.00


A: Static Structural
Equivalent Stress 5
Type: Equivalent (von-Mises) Stress
Unit: MPa
Time: 1
29/12/2020 15:12
90.529 Max
80.47
70.412
60.353
50.294
40.236
30.177
20.119
10.06
0.001377 Min
ANSYS
R19.2
Max
0.00
700.00 (mm)
350.00


A: Static Structural
Equivalent Stress 4
Type: Equivalent (von-Mises) Stress
Unit: MPa
Time: 1
29/12/2020 15:13
27.814 Max
24.724
21.633
18.543
15.453
12.362
9.2716
6.1812
3.0907
0.00027617 Min
ANSYS
R19.2
Max
0.00
500.00 (mm)
250.00


A: Static Structural
Total Deformation
Type: Total Deformation
Unit: mm
Time: 1
29/12/2020 15:14
0.14872 Max
0.1322
0.11567
0.099149
0.082624
0.066099
0.049574
0.03305
0.016525
0 Min
ANSYS
R19.2
Max
0.00
700.00 (mm)
350.00

Tail pulley

Item	Component	S_y	S_u	S_n (Estimated Fatigue Strength – ksi)						σ_{VM}		FS_{Sy}	FS_{Sn}
		ksi(Mpa)	ksi(Mpa)	$S_{n'}$	Mpa	ksi	-	-	Sn	Mpa	ksi	-	-
01	Shaft	60(655)	95(414)	38.0	0.8	1.0	0.9	0.7	19.2	90.5	13.0	7.2	1.5
02	Compression Hub	55(379)	90(620)	34.0	0.8	1.0	0.5	1.0	13.6	27.8	4.0	13.6	3.4
03	Key	55(379)	90(620)	34.0	0.8	0.8	0.5	1.0	10.9	27.8	4.0	13.6	2.7
04	Hub welded to Disc	36(250)	58(400)	22.0	0.8	1.0	0.9	1.0	15.8	32.9	4.7	7.6	3.3
05	Disc	36(250)	58(400)	22.0	0.8	1.0	0.9	1.0	15.8	28.4	4.1	8.8	3.9
06	Drum	36(250)	58(400)	22.0	0.8	1.0	0.9	1.0	15.8	16.2	2.3	15.4	6.8

$S_{n'}$: Modified fatigue strength in ksi – Source: (Mott, 2006)

C_m: Material factor – Source: (Mott, 2006)

C_{ts}: Type of stress factor $C_{ts}: 1$ para for bending stress $C_{ts}: 1$ for axial tension – Source: (Mott, 2006)

C_r: Reliability factor $C_r: 0.9$ for 90% reliability $C_r: 0.5$ for 100% reliability - Source : (Mott, 2006)

C_s: Size factor $C_r: 0.7$ for shaft diameter 50mm<D<250mm – Source: (Mott, 2006)

σ_{VM}: Von Mises stress

FS_{Sy}: Safety factor in yielding

FS_{Sy}: Safety factor in fatigue

Item	Component	Material	S_y	S_u
			ksi(Mpa)	ksi(Mpa)
01	Shaft	SAE 4140 HR	60(655)	95(414)
02	Compression Hub	SAE 1045	55(379)	90(620)
03	Key	SAE 1045	55(379)	90(620)
04	Hub welded to Disc	ASTM A36	36(250)	58(400)
05	Disc	ASTM A36	36(250)	58(400)
06	Drum	ASTM A36	36(250)	58(400)

Tail Pulley
Vibration Assessment:

$$w_{r1}: 0.97\ \frac{rad}{s}$$

w_{r1}: Angular velocity of the driving pulley

$$T_{rm}: \frac{2\pi}{w_{r1}} = 6.46\ s$$

$$f_{rm}: \frac{1}{T_{rm}} = 0.15\ Hz$$

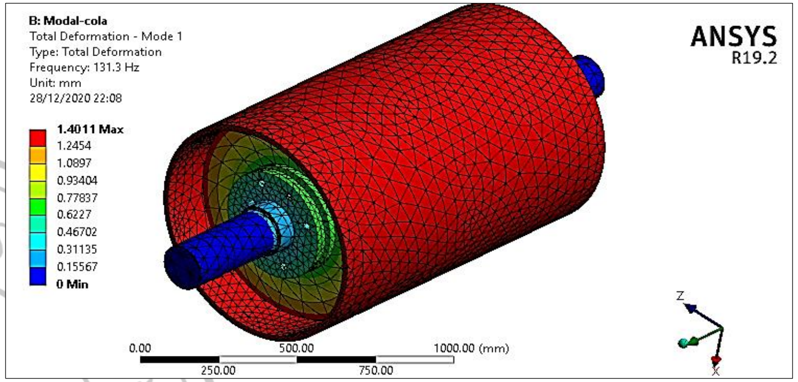
T_{rm}: Operating period of the driving pulley system

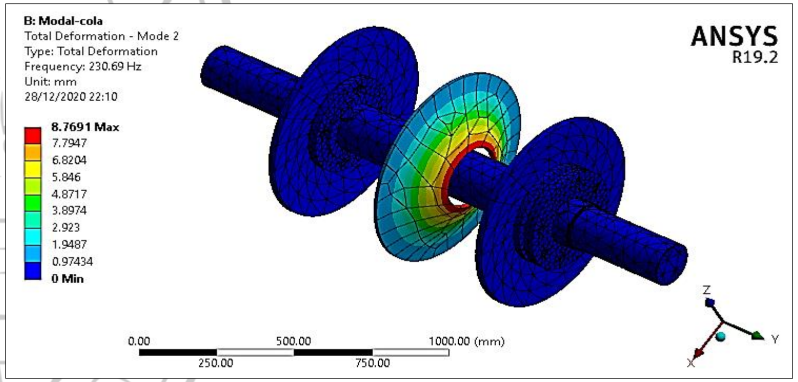
f_{rm}: Operating frequency of the driving pulley system

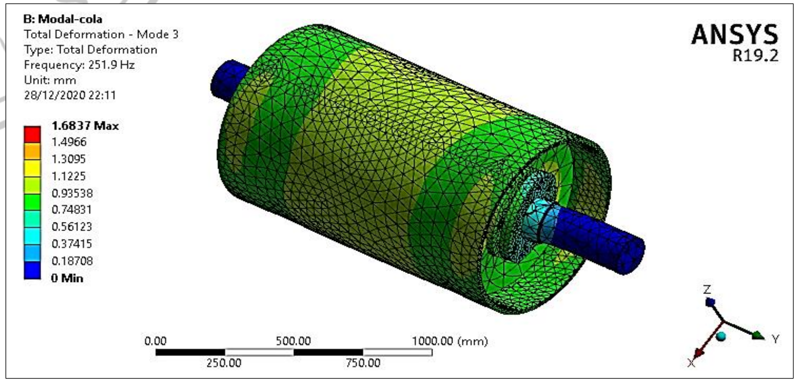
$$f_{rn}: 131.3\ Hz$$

f_{rn}: Natural frequency of the driving pulley system in the first vibration mode.

$$f_{rn} \gg f_{rm}\ (ok)$$



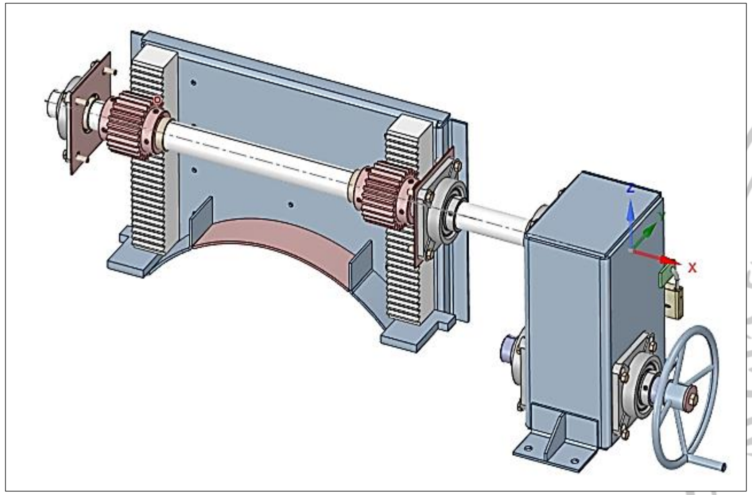


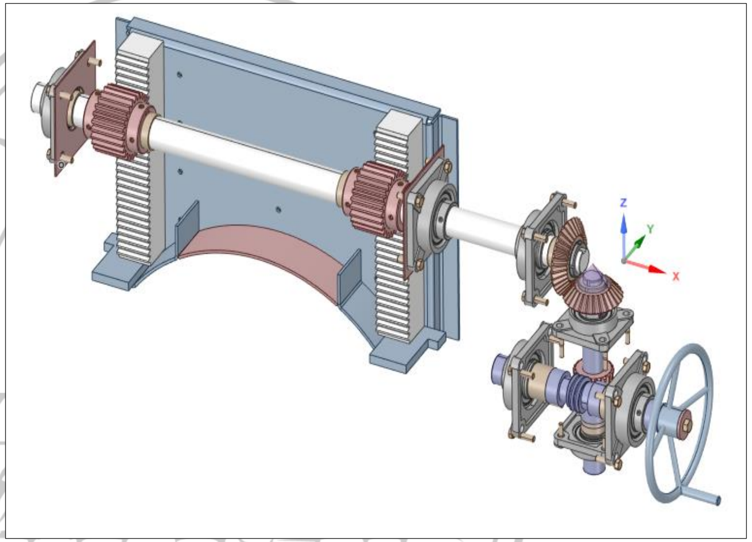


3.5.6 Gear Gate Calculation

Standards and Codes Related to the Mechanical Design of Gears

ANSI/AGMA Calculation methods for involute Spur and helical gear Teeth 2001-D04





$Z_{sf}: 20$

$n_{iw}: 1$

Z_{sf}: Number of teeth on the worm gear wheel

n_{iw}: Number of threads of the worm

$Z_{c1}: 30$

$Z_{c2}: 26$

Z_{c1}: Number of teeth on the driven bevel gear

Z_{c2}: Number of teeth on the driving bevel gear

$\tan(\lambda)\cos(\phi_n) < f_{sk1,sk2}$

$f_{sk1,sk2}: 0.15 - 0.09$

$f_{sk1,sk2}$: Minimum static and dynamic steel–steel friction coefficient.

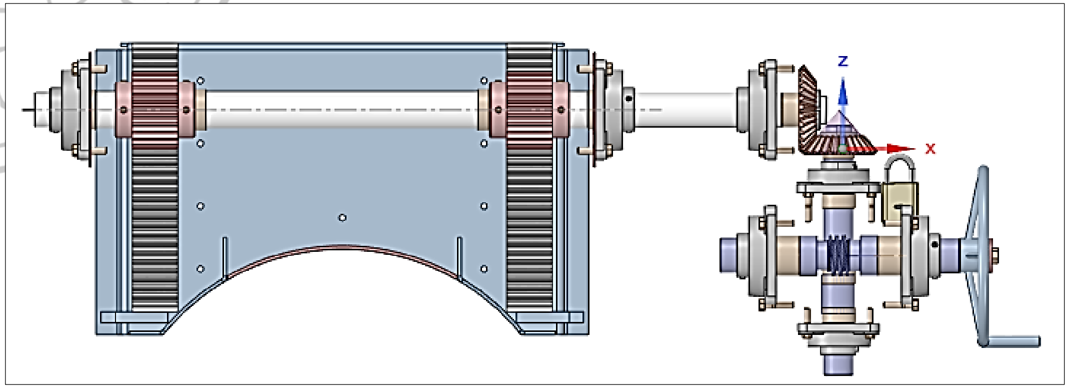
$\lambda: 3.57°$

$\phi_n: 25°$

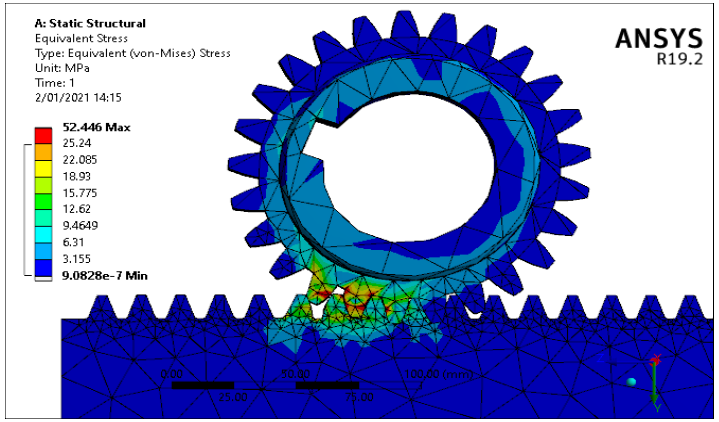
λ: Helix angle of the worm.

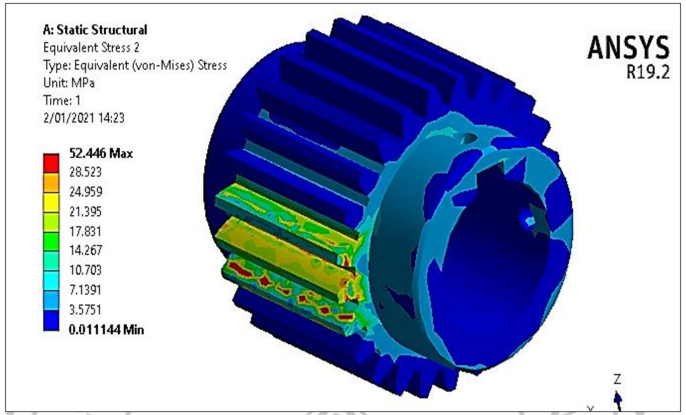
ϕ_n: Pressure angle of the worm.

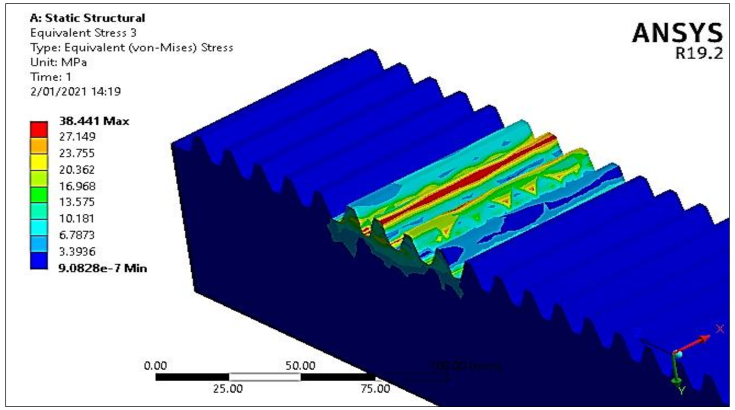
$0.056 < 0.09\ (ok)$

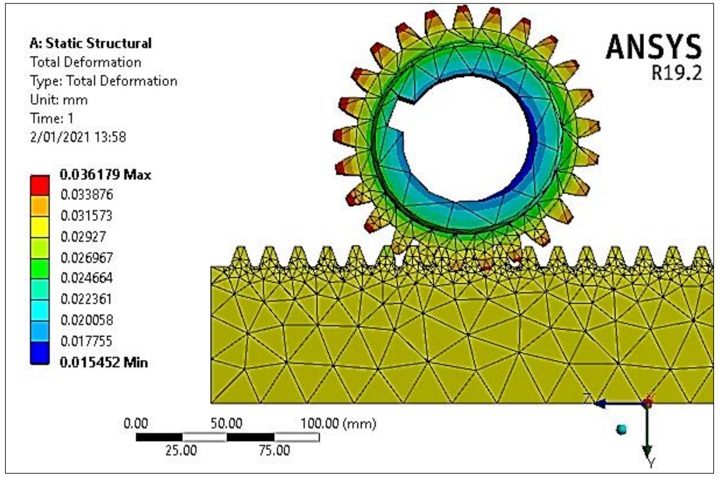


Rack Calculation









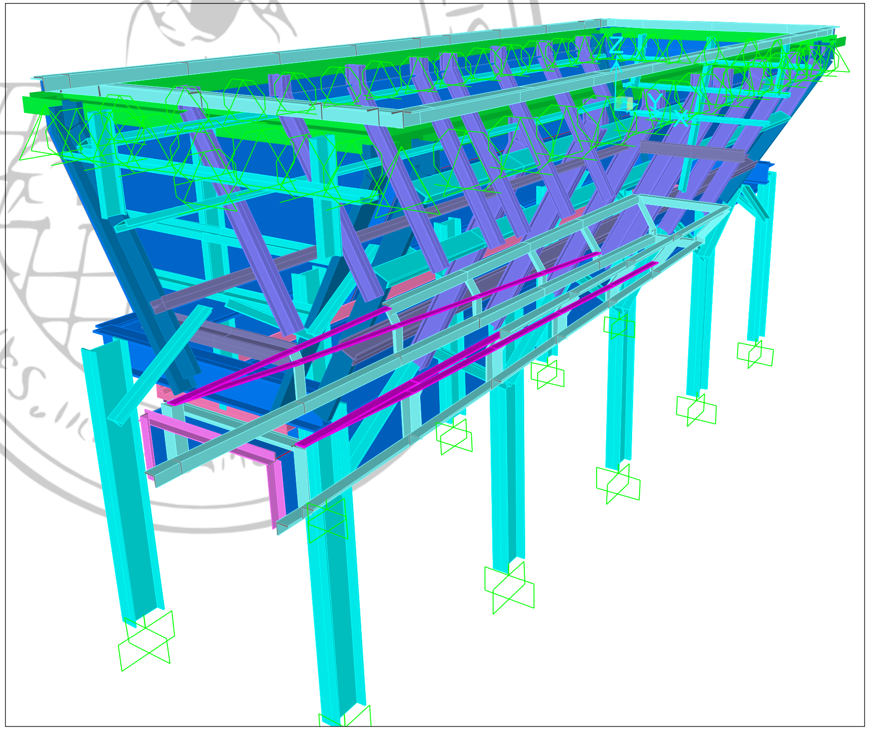
Component	Material	S_y	S_u	S_n (Estimated Fatigue Strength – ksi)						σ_{VM}		FS_{Sy}	FS_{Sn}
		ksi(Mpa)	ksi(Mpa)	$S_{n'}$	C_m	C_{ts}	C_r	C_s	S_n	Mpa	ksi	-	-
Rack Gear	SAE 1045	55(379)	90(620)	34.0	0.8	1.0	0.5	1.0	13.6	52.4	7.6	7.2	1.8
Rack	SAE 1045	55(379)	90(620)	34.0	0.8	1.0	0.5	1.0	13.6	38.4	5.5	9.9	2.5

3.6 Structural Calculation of Receiving Hopper

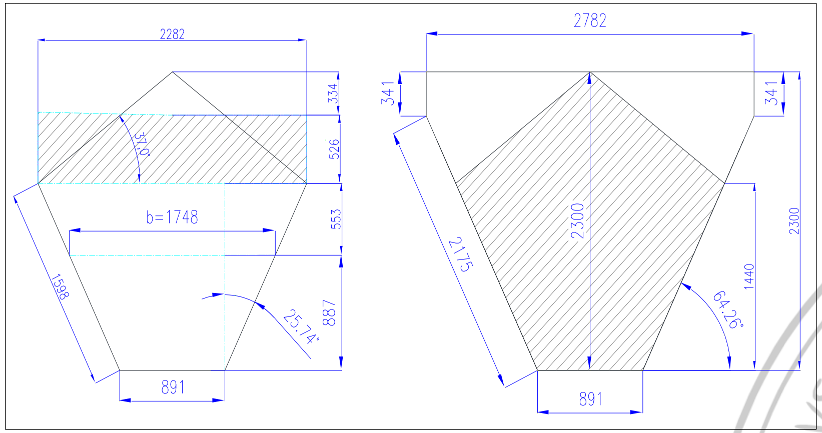
NTP	Peruvian Technical Standards	RNE 020/030 2018
AISC	American Institute of Steel Construction	AISC 360-16
ASCE	American Society of Civil Engineers	ASCE 7-16
AWS	American Welding Society.	D1.1/D1.1M:2006
Eurocode 1	Actions on structures Silos and tanks	Part 4
SSPC-SP-10	Surface Preparation Specification	NACE-2

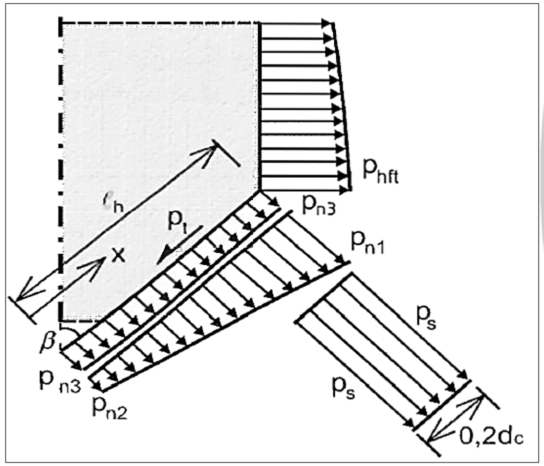
Load Combinations:

- C1=1.4D
- C2=1.2D+1.6L
- C3=1.2D+Ev±Eh+L
- C4=0.9D-Ev±Eh



Live load due to particulate material (Dead load: Self-weight)





- Inclined distance from the apex of the hopper to the transition: l_h
- Normal pressure on the inclined wall of the hopper: P_n
- Components of normal pressure on the inclined wall of the hopper (i=1,2,3) P_{ni}
- Transition pressure at the discharge: P_s
- Horizontal pressure at the transition: $Phft = Phf$
- Frictional wall pressure: P_t

$$P_{n1} = Pvft(Cb\sin^2\beta + \cos^2\beta) = 12.70\ kPa$$

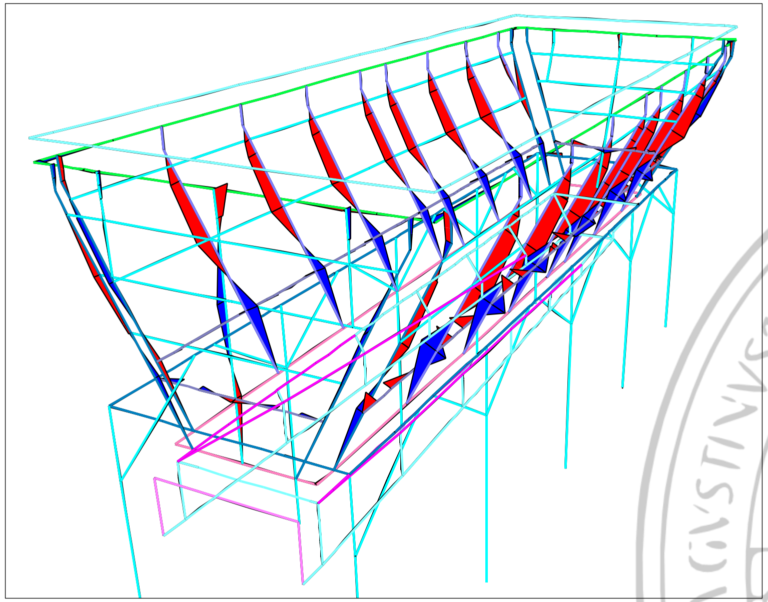
$$P_{n2} = Pvft(Cb\sin^2\beta) = 2.95\ kPa$$

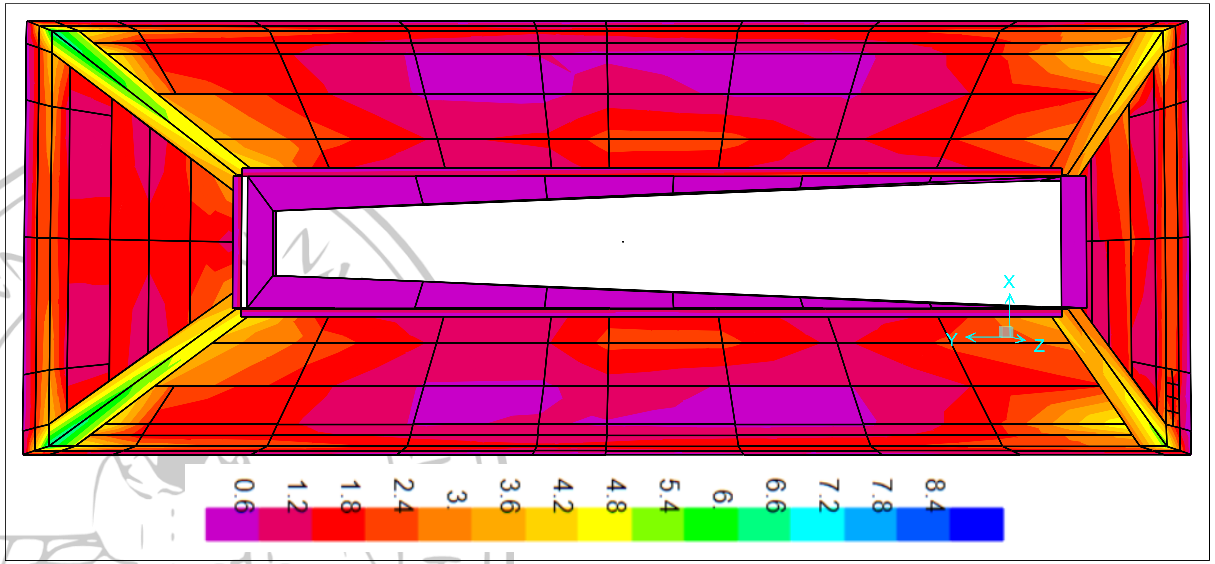
$$P_{n3} = \frac{3A}{U\sqrt{\mu_h}}\gamma k(\cos^2\beta) = 28.55\ kPa$$

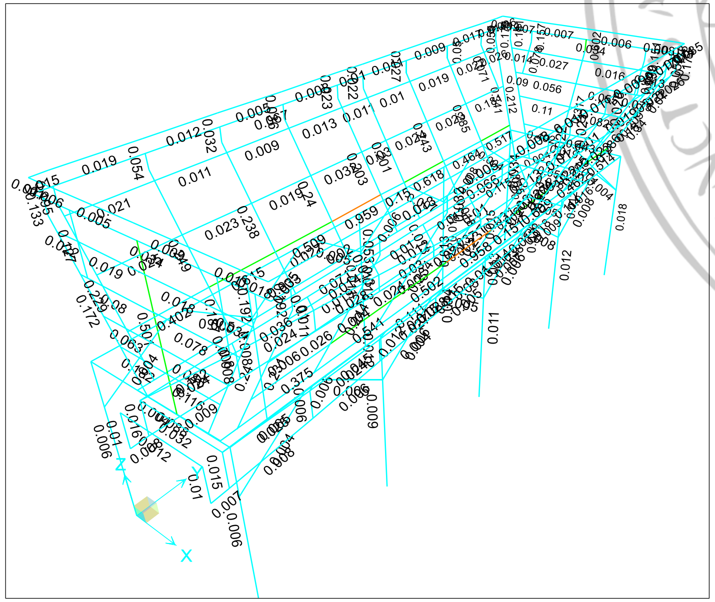
Seismic Load

- Z: 0.45 (Zona 4) Source: (TISUR, 2019)
- U: 1.00 (“C” Common Buildings) Source: (National Building Regulations, 2018)
- R: 4.00 (Seismic Force Reduction Coefficient) Source: (TISUR, 2019)
- S: 1.00 (“S1” Soil Factor) Source: (TISUR, 2019)
- C: 2.50 (Seismic Amplification Factor) Source: (TISUR, 2019)

Results of structural analysis of receiving hopper



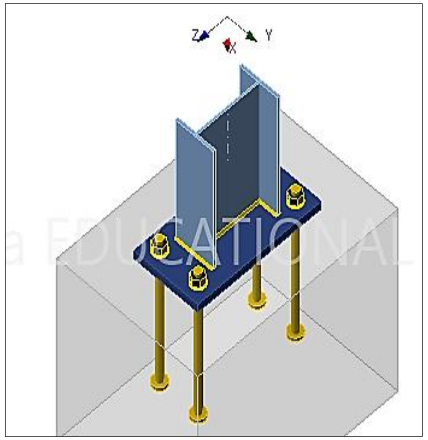


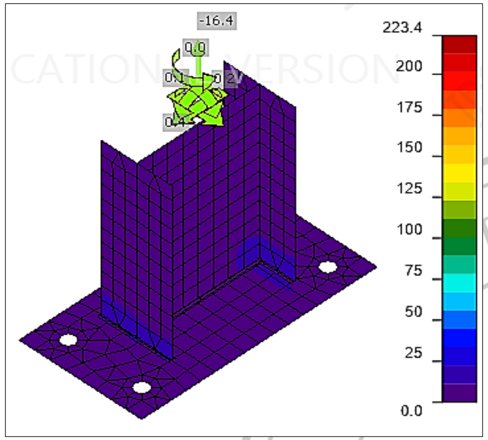


Item	Case	Mode	Direction	Static Participation	Dynamic Participation
01	MODAL	Acceleration	UX	100.0	95.8
02	MODAL	Acceleration	UY	100.0	90.6
03	MODAL	Acceleration	UZ	100.0	80.7

Item	Case	Model	X (kN)	Y (kN)	Z (kN)
01	QUAKEx	Linear	-75.5	0.0	0.0
02	QUAKEy	Linear	0.0	-75.5	0.0
03	QUAKEz	Linear	0.0	0.0	50.3
04	QUAKE Dynamic x	Spectral Response	75.5	1.4	4.8
05	QUAKE Dynamic y	Spectral Response	2.1	75.5	11.5
06	QUAKE Dynamic z	Spectral Response	5.3	5.8	56.5

Results of structural analysis of receiving hopper





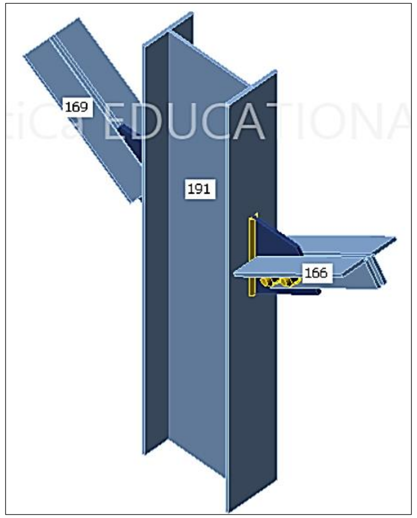
Check of members and steel plates for extreme load effect

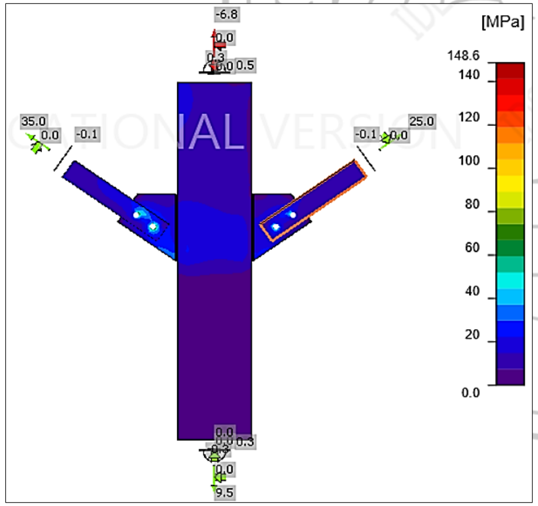
	Status	Item	Th [mm]	Loads	σ,Ed [MPa]	ε,Pl [%]	σc,Ed [MPa]
	✓	33-bfl 1	9.1	C2	21.7	0.0	0.0
	✓	33-tfl 1	9.1	C2	18.8	0.0	0.0
	✓	33-w 1	6.1	C2	21.4	0.0	0.0
>	✓	BP1	25.0	C2	14.5	0.0	0.0

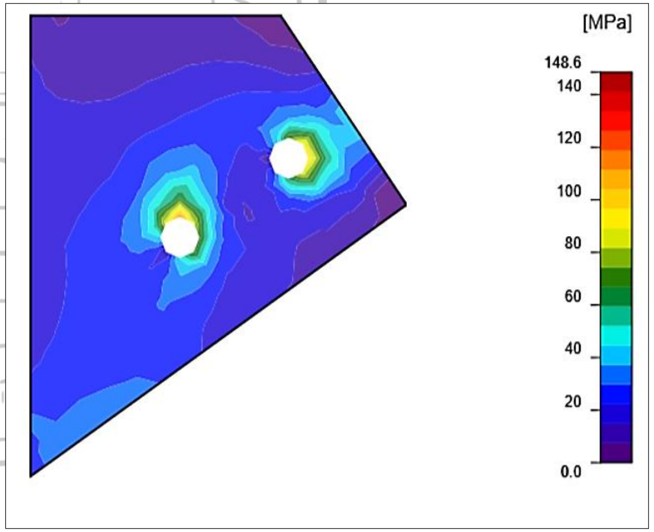
Design data

	Grade	Fy [MPa]	ε,lim [%]
>	A36	248.2	5.0

The critical component is subjected to a combined stress under the Von Mises criterion of 21.7 MPa, as indicated in illustration 244. Comparing this value with Fy (250 MPa), a safety factor of 11.5 is obtained.







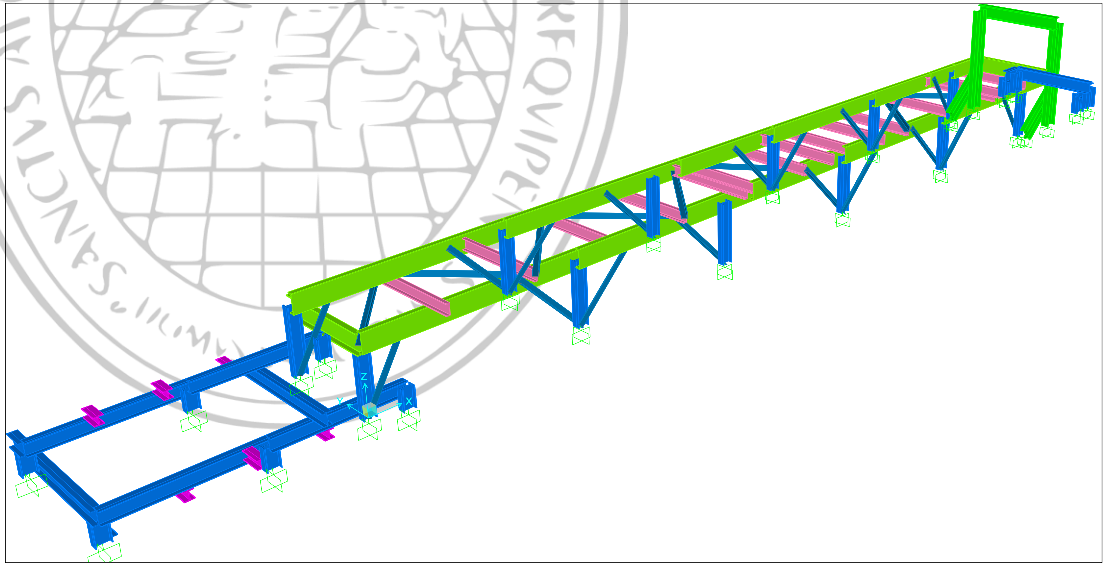
The critical component is subjected to a combined stress under the Von Mises criterion of 94.6 MPa, as indicated in illustration 253. Comparing this value with Fy (250 MPa), a safety factor of 2.64 is obtained.

3.7 Structural calculation of conveyor belt

NTP	Peruvian Technical Standards	RNE 020/030 2018
AISC	American Institute of Steel Construction	AISC 360-16
ASCE	American Society of Civil Engineers	ASCE 7-16
AWS	American Welding Society.	D1.1/D1.1M:2006
SSPC-SP-10	Surface Preparation specification	NACE-2
CEMA	Belt conveyor for bulk materials/Conveyor equipment manufacturers association	6th Edition

Load combinations

- C1=1.4D
- C2=1.2D+1.6L
- C3=1.2D+Ev±Eh+L
- C4=0.9D-Ev±Eh



Live and dead loads on the conveyor belt

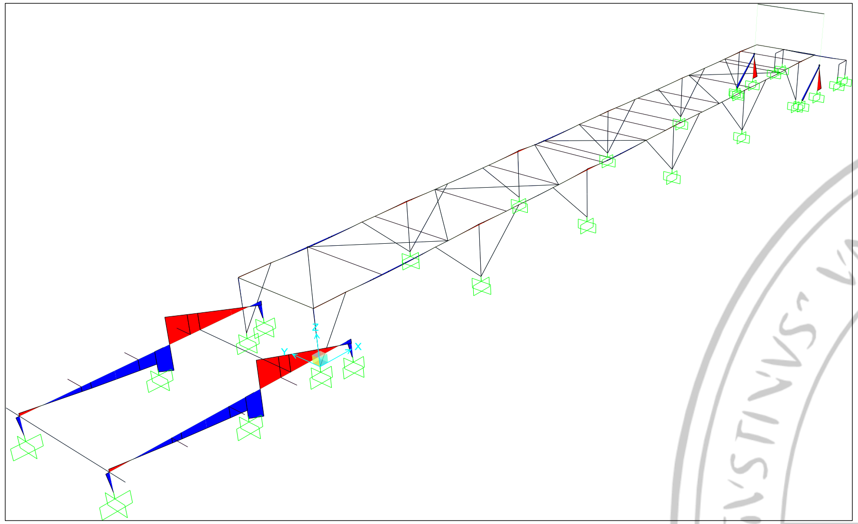
Dead Load by Conveyor Belt Components					
Item	Description	Quantity	Unit Weight (Kg)/Linear meter weight (kg/m)	Total (kg)	Total (kN)
01	Self-weight of the structure	1 und	2093.7	2093.7	20.5
02	Carrying Idler Cema E5	5 und	45.0	225.0	2.2
03	Return Idler Cema E5	5 und	44.0	220.0	2.2
04	Impact Idler Cema E5	26 und	62.0	1612.0	15.8
05	Self-aligning Carrying Idler Cema E5	2 und	50.0	100.0	1.0
06	Self-aligning Return Idler Cema E5	1 und	50.0	50.0	0.5
07	Drive Pulley Ø30” (shaft + drum + lining)	1 und	1631.0	1631.0	16.0
08	Tail Pulley Ø30” (shaft + drum + lining)	1 und	1089.0	1089.0	10.7
09	Head Pulley Bearing (SAF22544)	2 und	279.0	558.0	5.5
10	Tail Pulley Bearing (SAF22536)	2 und	150.0	300.0	2.9
11	Drive Pulley Carriage	2 und	91.0	181.9	1.8
12	Conveyor Belt 42” (1067mm) wide EP 1250/4 Fabric (4-Ply) Cover thickness/total thickness approx. 21.7 mm	13.5 m	64.0 (27kgf/m for two runs, round trip, plus pulley portion)	862.1	8.5
13	Upper Guards	13.5 m	69.2	934.3	9.2
14	Skirts	5.84 m	95.9	560.2	5.5
15	Lower Guards	10 m	6.0	60.0	0.6
16	Gate	1 und	232.0	232.0	2.3
17	Transition Chute	1 und	750.0	750.0	7.4
18	Primary Cleaner CØ#1I-HD	2 und	40.0	80.0	0.8
19	Return Belt Cleaner V	1 und	32.0	32.0	0.3
Total (kg/kN)				**11571.3**	**113.5**

Live and dead loads on the conveyor belt

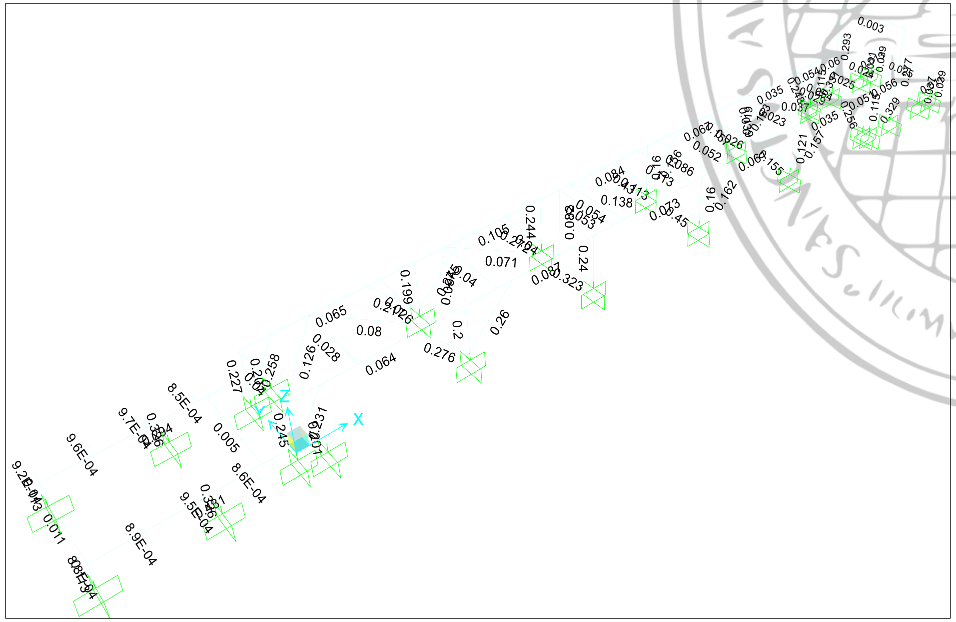
Live and dead loads on the conveyor belt							
Item	**Description**	**Quantity**	**Unit**	**Unit Weight (kg) / Linear Weight (kg/m)**	**Total (kg)**	**Total (kN)**	**Direction**
01	Gear motor 60 HP (+25% per E020 standard)	1	unit	1140.0	1425.0	14.0	-z
02	Backstop (+25% per E020 standard)	1	unit	263.0	328.8	3.2	-z
03	Drive tension T1	1	unit	18695.2	18695.2	183.4	-x
04	Drive tension T2	1	unit	7571.5	7571.5	74.3	-x
05	Drive tension T2	1	unit	1688.3	1688.3	16.6	z
06	Tail tension T1	1	unit	18695.2	18695.2	183.4	x
07	Tail tension T2	1	unit	7738.5	7738.5	75.9	x
08	Tail tension T2	1	unit	541.1	541.1	5.3	z
09	Ore load capacity	13.44	m	124.6	1675.2	16.4	-z
10	Hydraulic tensioning load	2	unit	13256.0	26512.0	260.1	x
Total -z (kg/kN)					**3428.9**	**33.6**	

Seismic load identical to the receiving hopper due to the same location

Results of the Structural Analysis of the Conveyor Belt

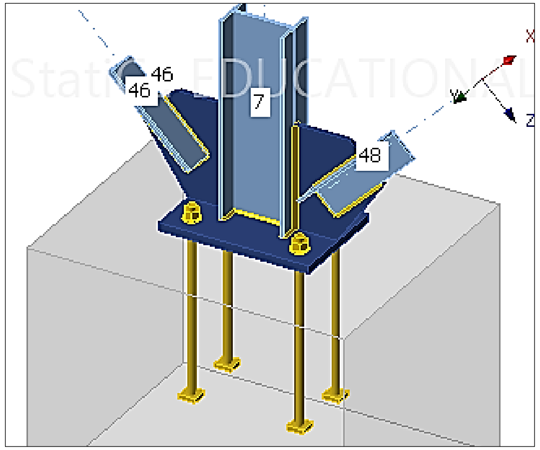


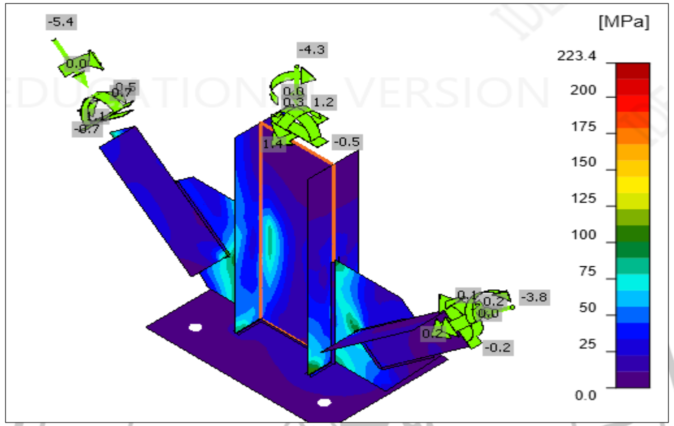
Item	Case	Mode	Direction	Static Participation	Dynamic Participation
1	MODAL	Acceleration	UX	100.0	92.0
2	MODAL	Acceleration	UY	100.0	96.5
3	MODAL	Acceleration	UZ	100.0	81.8

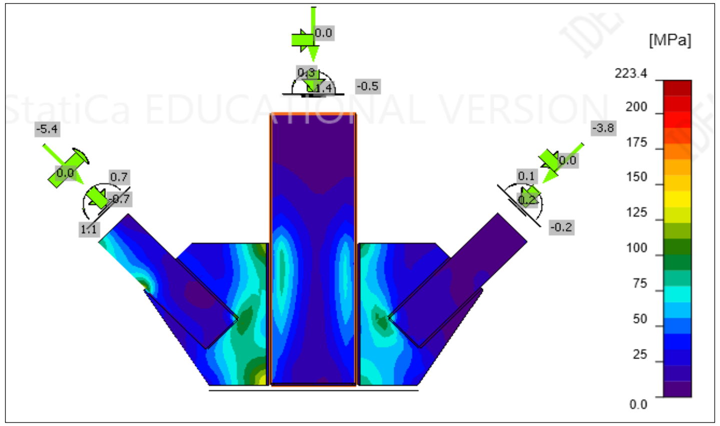


Case	Model	X (kN)	Y (kN)	Z (kN)
QUAKEx	Linear	-34.29	0.00	0.00
QUAKEy	Linear	0.00	-34.29	0.00
QUAKEz	Linear	0.00	0.00	22.86
QUAKE Dynamic x	Spectral response	34.29	4.51	11.69
QUAKE Dynamic y	Spectral response	6.55	34.29	2.36
QUAKE Dynamic z	Spectral response	9.57	0.87	35.13

Results of the Structural Analysis of the Conveyor Belt







Check of anchors for extreme load effect

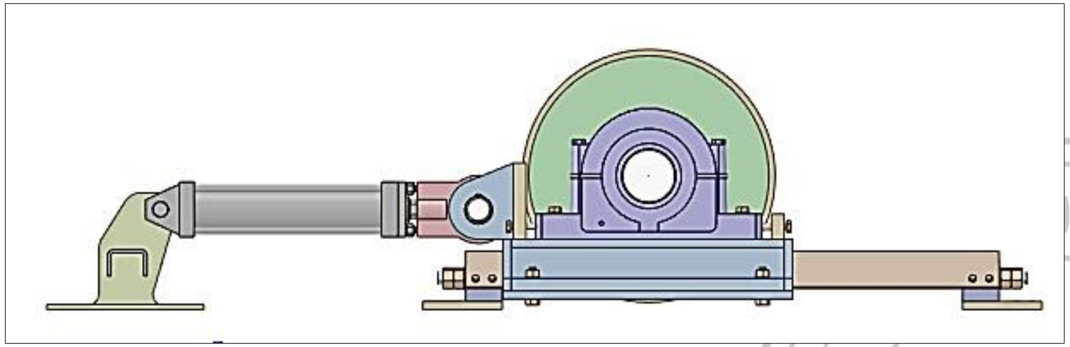
		Status	Item	Grade	Loads	Nf [kN]	V [kN]	ϕNcbg [kN]	ϕNp [kN]	ϕNsb [kN]	ϕVcbg [kN]	ϕVcp [kN]	Utt [%]	Uts [%]	Utts [%]
	+	✓	A5	3/4 A325 - 1	C2	0.0	0.3	-	203.1	-	39.0	290.1	0.0	3.3	0.3
>	+	✓	A6	3/4 A325 - 1	C3.4D	5.9	1.2	96.7	203.1	221.4	-	290.1	6.1	1.7	1.1
	+	✓	A7	3/4 A325 - 1	C3.4D	0.0	0.8	-	203.1	-	46.6	290.1	0.0	2.2	0.2
	+	✓	A8	3/4 A325 - 1	C3.4D	0.0	0.8	-	203.1	-	67.4	290.1	0.0	1.5	0.1

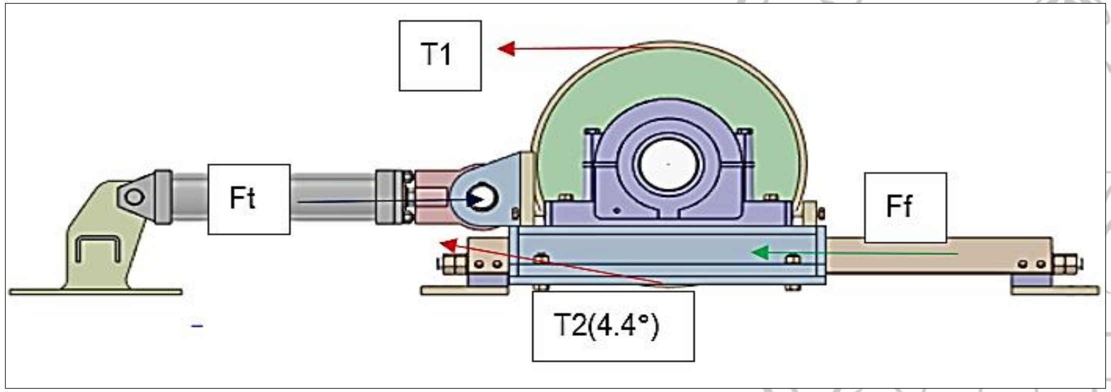
Check of welds for extreme load effect (Plastic redistribution)

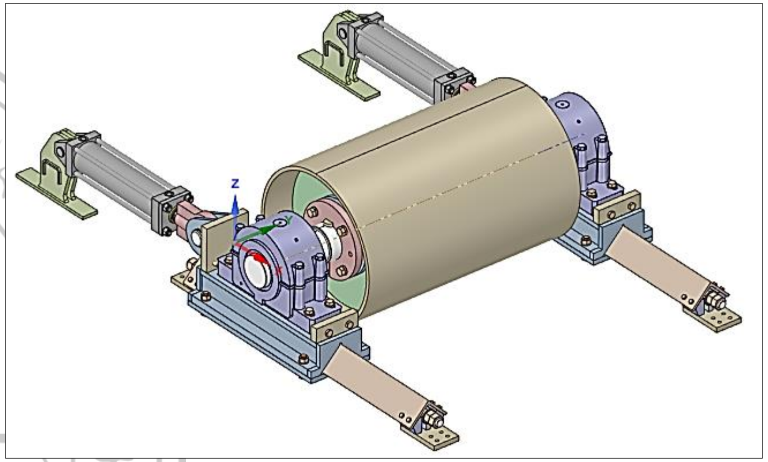
		Status	Item	Edge	Xu	Th [mm]	Ls [mm]	L [mm]	Lc [mm]	Loads	Fn [kN]	ϕRn [kN]	Ut [%]
	+	✓	BP1	7-bfl 1	E70xx	◢5.7◣	◢8.0◣	101	20	C3.4D	2.8	35.6	7.9
	+	✓			E70xx	◢5.7◣	◢8.0◣	101	20	C3.4D	4.0	36.5	10.9
	+	✓	BP1	7-tfl 1	E70xx	◢5.7◣	◢8.0◣	101	20	C3.4D	5.4	34.7	15.4
	+	✓			E70xx	◢5.7◣	◢8.0◣	101	20	C3.4D	6.9	36.3	19.0
	+	✓	BP1	7-w 1	E70xx	◢5.7◣	◢8.0◣	145	18	C3.4D	1.3	27.0	4.7
	+	✓			E70xx	◢5.7◣	◢8.0◣	146	18	C3.4D	1.7	23.5	7.3
	+	✓	7-tfl 1	SP1	E70xx	◢5.7◣	◢8.0◣	248	16	C3.4D	2.9	21.2	13.7
	+	✓			E70xx	◢5.7◣	◢8.0◣	248	16	C3.4D	2.5	21.9	11.5
	+	✓	7-bfl 1	SP2	E70xx	◢5.7◣	◢8.0◣	249	16	C3.4D	5.5	25.7	21.6
	+	✓			E70xx	◢5.7◣	◢8.0◣	249	16	C3.4D	3.7	28.1	13.2
	+	✓	SP2	46-bfl 1	E70xx	◢4.2	◢6.0	73	10	C3.4D	4.4	12.9	34.5
	+	✓	SP1	48-w 1	E70xx	◢4.2	◢6.0	73	10	C3.4D	4.0	13.3	30.4
	+	✓	SP2	46-bfl 1	E70xx	◢4.2	◢6.0	148	10	C3.4D	2.5	9.7	25.9
>	+	✓	SP2	46-bfl 1	E70xx	◢4.2	◢6.0	148	10	C3.4D	5.5	10.9	50.9
	+	✓	SP1	48-w 1	E70xx	◢4.2	◢6.0	147	10	C3.4D	0.8	9.5	8.7
	+	✓	SP1	48-w 1	E70xx	◢4.2	◢6.0	148	10	C3.4D	4.4	10.6	41.7

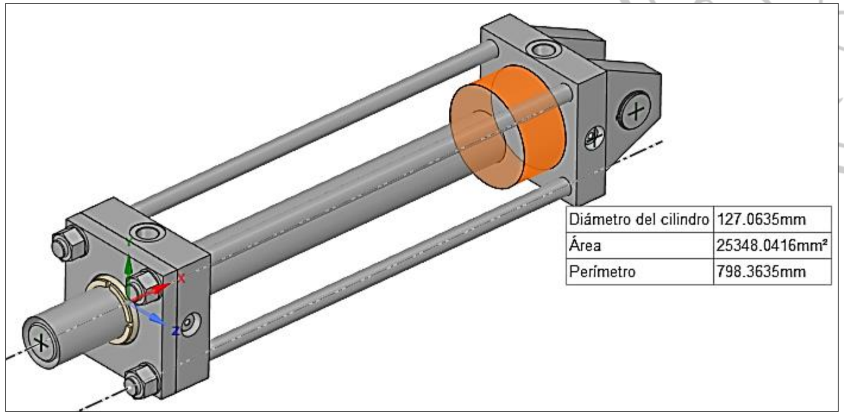
The critical component is subjected to a combined stress under the Von Mises criterion of 128.4 MPa, as shown in Illustration 329. Comparing this value with Fy (250 MPa), a safety factor of 1.94 is obtained.

3.7 Calculation of the Hydraulic Tensioning System

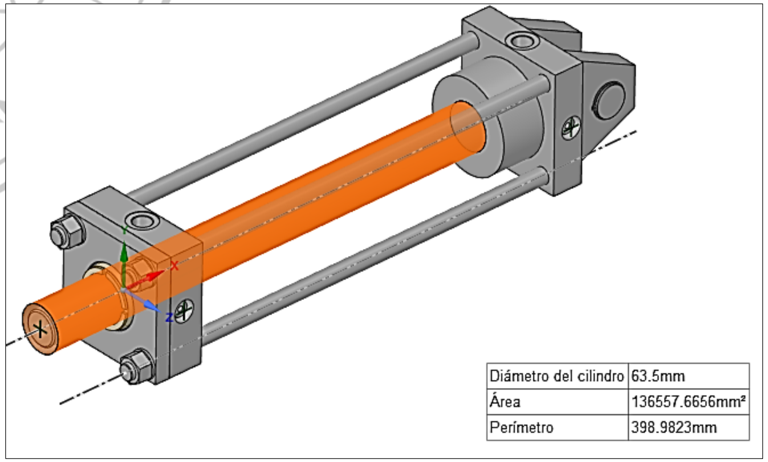








Diámetro del cilindro	127.0635mm
Área	25348.0416mm²
Perímetro	798.3635mm



Diámetro del cilindro	63.5mm
Área	136557.6656mm²
Perímetro	398.9823mm

3.7 Calculation of the Hydraulic Tensioning System

For the first iteration, a working pressure of 125 bar is considered.

$$A_{p1}: \frac{F_{c1}}{P_{c1}} = 10400 mm^2$$

A_{p1}: Iterative piston area

P_{c1}: Iterative working pressure

$$D_{p1}: \sqrt{\frac{4A_{p1}}{\pi}} = 115 mm$$

Normalizing piston diameter according to Parker catalog:

$$D_{p2}: 5\ in = 127 mm$$

$$P_{c2}: \frac{F_{c1}}{A_{p2}} = 102.6\ bar$$

Verification of the flow required for the rod extension

$$Ve: 21\ \frac{mm}{s}$$

$$Q: 2A_{p2}Ve = 31.9\ \frac{l}{min}$$

$$Q_t: 5\ Q = 160\ L$$

Q_t: Tank volume

$$n_b: 1750\ \frac{rev}{min}$$

n_b: Rotational speed of gear pump

$$CCR_1: \frac{Q}{n_b} = 21.46 \frac{cm^3}{rev}$$

η_v: Volumetric efficiency

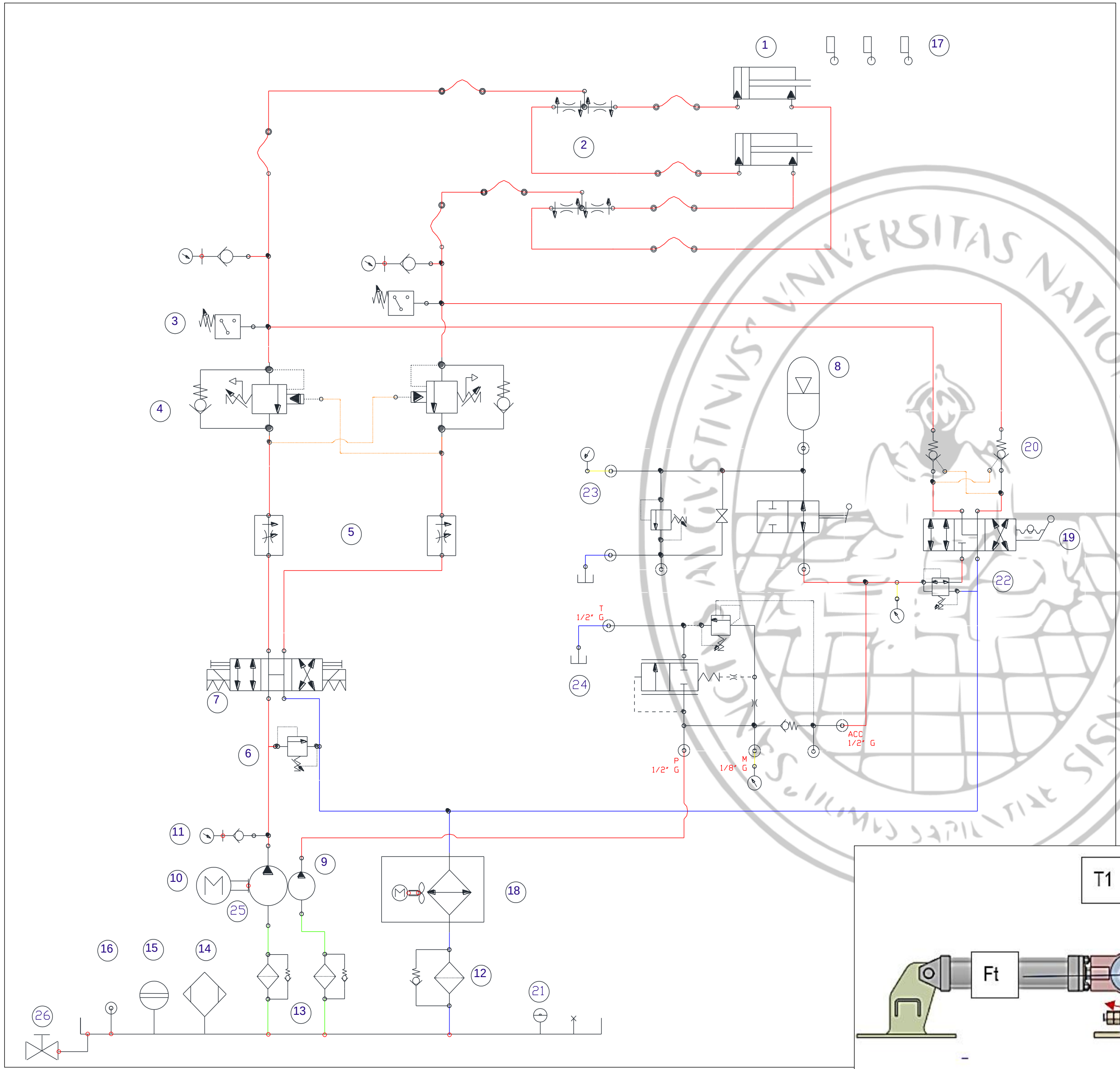
CCR_1: Tensioning system pump unit

$$CCR_1': 22.8 \frac{cm^3}{rev}$$

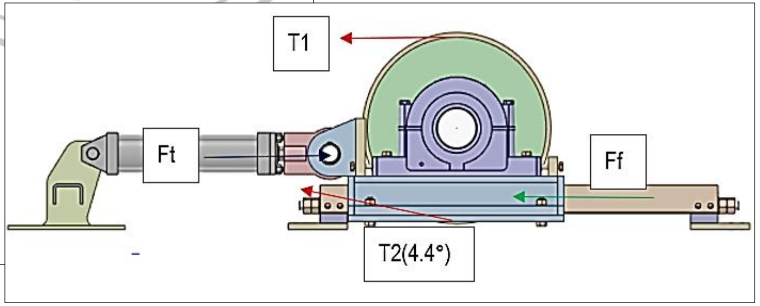
The 24.8 L resulting from the estimation are standardized, and a 25 L accumulator is selected.

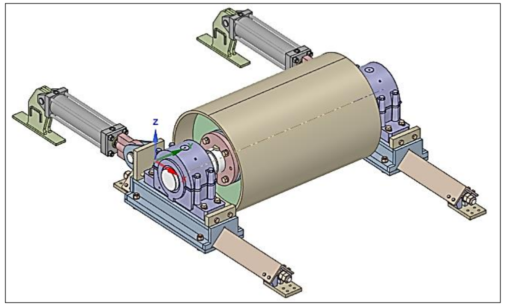
$$HP_{b1} = P_{b1} Q \frac{1}{\eta_t} + P_{b2} Q_2 \frac{1}{\eta_t} = 22.26\ hp$$

3.7 Calculation of the Hydraulic Tensioning System

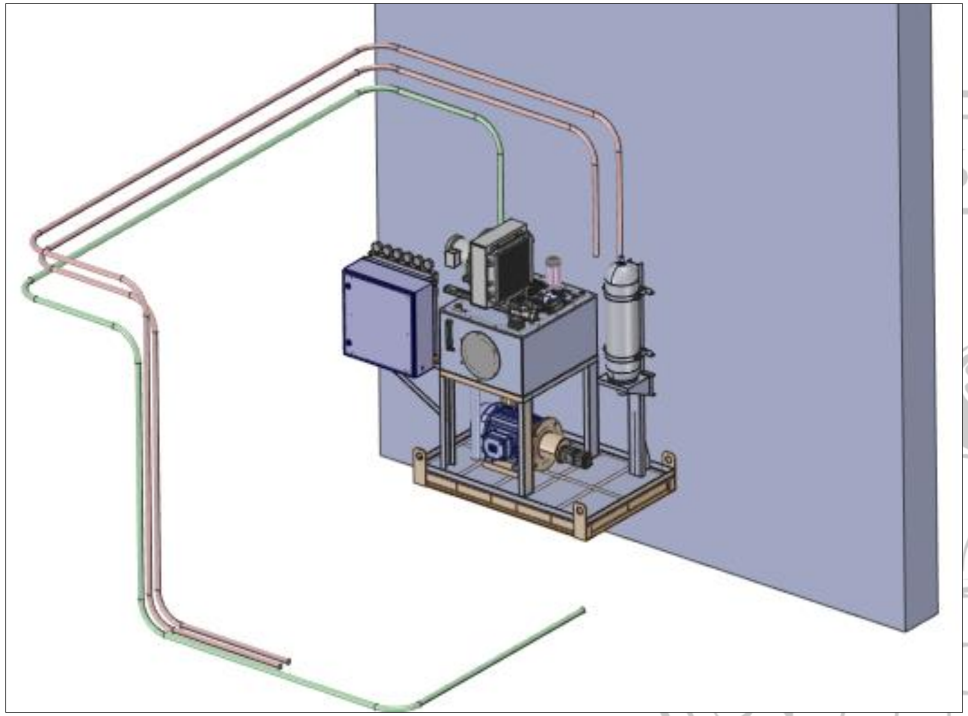


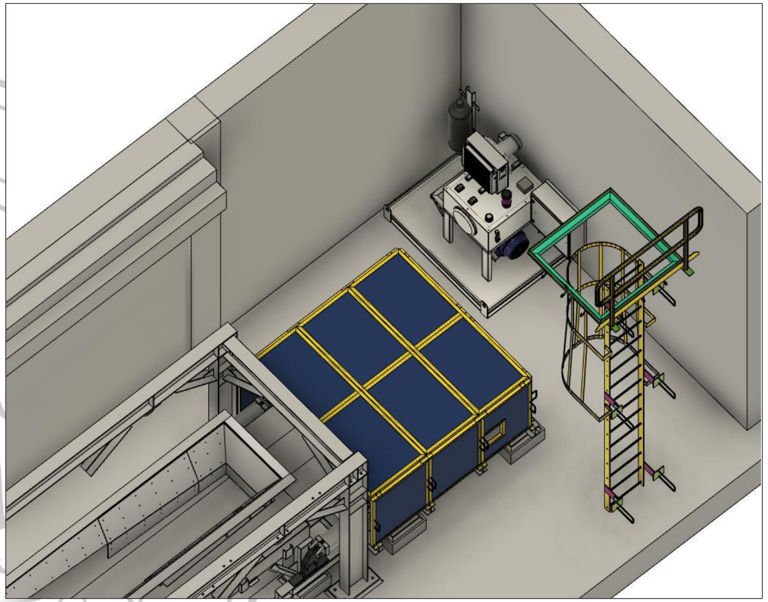
Item	Qty	Description	Brand
1	2	Hydraulic cylinder 5"x2.5"x19.7"	PARKER
2	2	Flow divider 50-50	DANFOSS
3	1	Pressure switch 200 bar	FOX
4	1	Double counterbalance valve	DANFOSS
5	2	Pressure-compensated flow regulator	PARKER
6	1	Pressure relief valve	PARKER
7	1	4/3 directional solenoid valve	PARKER
8	1	Hydraulic bladder accumulator 25 L	FOX
9	1	Gear pump 22+4 CCR	DANFOSS
10	1	Electric motor 25 HP	WEG
11	5	Pressure gauge	PARKER
12	1	Return filter KLT	PARKER
13	2	Suction strainer	PARKER
14	1	Silica-gel breather filter	PARKER
15	1	Oil level indicator	PARKER
16	1	Oil filler plug	PARKER
17	3	Inductive stainless steel sensor	ALLEN BRADLEY
18	1	Air oil cooler, ULAC AC motor	PARKER
19	1	Manual directional valve	PARKER
20	1	Pilot-operated double check valve	PARKER
21	1	Low oil level switch	PARKER
22	1	Pressure reducing valve	PARKER
23	1	Accumulator safety and maintenance manifold	FOX
24	1	Accumulator charging manifold	FOX
25	1	Motor-pump coupling and bell housing	PARKER
26	1	Low-pressure ball valve for reservoir drain	PARKER





3.7 Calculation of the Hydraulic Tensioning System





Properties	Method	Tellus S2 M 68
Kinematic Viscosity @40 °C (cSt)	ASTM D445	68
Kinematic Viscosity @100 °C (cSt)	ASTM D445	8.6
Viscosity Index	ISO 2909	97
Density @15 °C (kg/l)	ISO 12185	0.886
Flash Point (COC) °C	ISO 2592	235
Pour Point °C	ISO 3016	-24

3.8 Selection of Components

3.8.1 Belt Selection

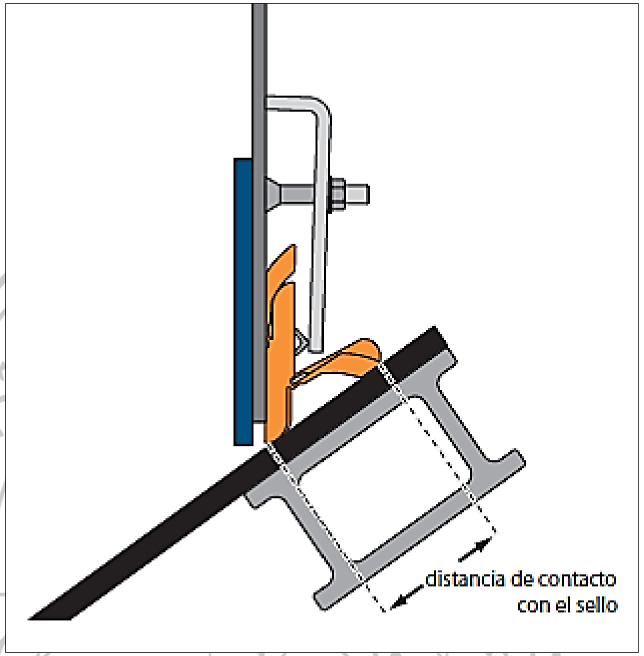
$$PIW_{1}: \frac{T_1}{b} = 171.94\ \frac{kN}{m}$$

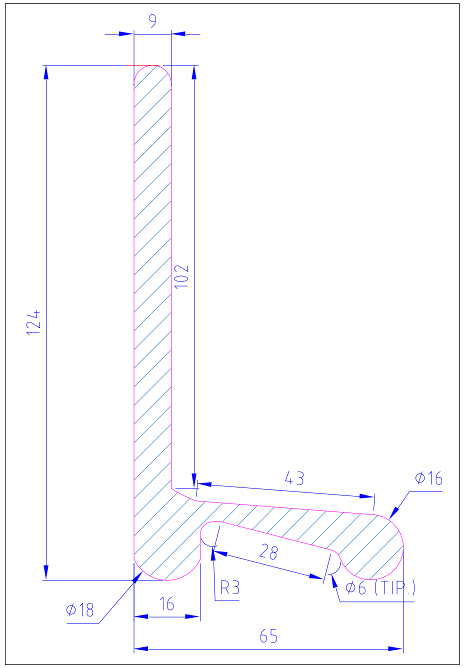
$$PIW'_{1}: \frac{T_{1o}}{b} = 155.14\ \frac{kN}{m}$$

$$Bs_{1}: 1250\ \frac{kN}{m}$$

$$FS_{b}: \frac{Bs_1}{PIW_1} = 7.27$$

$$FS_{bo}: \frac{Bs_1}{PIW'_1} = 8.05$$





3.8.2 Gear Motor Selection

The selection of the gear motor is based on the power required in the mechanical calculation of the conveyor belt. The power is standardized to the value offered in the catalog, with a rating of 45 kW (60 hp).

3.8.3 Selection of Bearing Housings and Bearings

$$C_i: P_1(L)^{\frac{1}{p}} = 455.2\ kN$$

C_i: Basic dynamic load rating for 100,000 hours of life

$$C_1: 1835\ kN$$

C_1: Equivalent dynamic load of the selected bearing

$$C_i < C_1 (ok)$$

$$C_{ii}: P_2(L)^{\frac{1}{p}} = 240.61\ kN$$

C_i: Equivalent dynamic load required for a service life of 100,000 hours

$$C_2: 1237\ kN$$

C: Equivalent dynamic load of the selected bearing

$$C_{ii} < C_2 (ok)$$

3.8 Selection of Components

3.8.1 Selection of Wear-Resistant Material TIVAR88

- Modified polyethylene / coefficient of friction 0.08 / Shore D64 hardness
- Promotes reliable and consistent bulk material flow
- Resistant to abrasion, chemicals, and corrosion
- Low coefficient of friction
- Does not absorb moisture
- Reduces or eliminates arching, ratholing, and erratic flow

4 Total Costs.

Costs of Feeding System – Receiving Hopper and Conveyor Belt with Hydraulic Tensioning		
Item	Description	Amount (USD)
1	Design and engineering of the receiving hopper	14,000.00
2	Design and engineering of the conveyor belt with hydraulic tensioning	16,000.00
3	Fabrication and installation of the receiving hopper	52,000.00
4	Fabrication and installation of the conveyor belt with hydraulic tensioning	65,000.00
Total		**147,000.00**

5 Conclusions

- The design of a copper concentrate feed conveyor belt was carried out, taking into account all technical parameters. The hydraulic tensioning system was effectively designed, as well as the belt components using finite element methodology. Finally, the proposed procedure reduced design time by 90% through the use of analysis software, a percentage obtained thanks to design evaluation with ANSYS, Idea Statica, and SAP2000.

- From the analysis of the input data, it is concluded that the internal friction angle of the material, which in this case is 35°, with an increment factor of 1.9 established by (The European Union, 2006), determines the shear load to be overcome in the feed hopper for transport, and consequently the main belt tension. That is, the drive belt tension is directly proportional to the variation of this factor.

- Pressures in the direct-discharge receiving hopper were established according to criteria defined by the European Union standard, which indicates that the equivalent height generates critical trapezoidal loads. Therefore, it is concluded that the required stiffness of the hopper structure depends on this factor.

- The calculations performed according to the standard proved to be consistent and were applied both to the mechanical design and the structural design, with a minimum safety factor value for mechanical components of 1.5 in the tail pulley and a maximum ratio of 0.958 for the structural component of hopper 2C 6x8.2, which is subjected to maximum dynamic pressure loads in the middle wall of the hopper.

5 Conclusions

- It is clear that the geometric definition of material hauling is determined by the effective belt width; however, it is also necessary to verify the absence of material spillage by configuring the side seal. To ensure no spillage, the appropriate geometry of a double-lip seal must be established.

- We can observe that in the design of the drive and tail pulleys, it is necessary to contrast the admissible fatigue stress with the combined Von Mises stress to which the pulley is subjected, since fatigue safety factors are representative (1.5 for the tail pulley and 1.9 for the drive pulley). In addition, verifying the vibration modes of the pulleys to obtain their natural frequencies through a finite element modal analysis and ensuring non-resonance completes the mechanical design of the pulley.

- The selection of mechanical components for the conveyor belt is carried out following a procedure specified by the manufacturer in its technical specification.

- It is also concluded that the hydraulic system defined for the design of the feed conveyor belt meets the requirements for the standardization of automatic tensioners in conveyor belt variants of different configurations and lengths. This can be considered a significant contribution to conveyor belt engineering.

- Finally, it is concluded that in order to present the results obtained in the design of the entire feeding system, it is necessary to provide detailed general, assembly, and installation drawings.

6 References

American Institute of Steel Construction. (2016). *Specification for Structural Steel Buildings ANSI/AISC 360-16*. Chicago, Illinois: AISC.
American Society of Civil Engineers. (2017). *ASCE 7-16 Minimum Design Loads and Associated Criteria for Buildings and Other Structures*. Reston, Virginia, USA: ASCE Standard.
Ccolque, A. C. (2017). *Quality of Splicing and Vulcanization of ST 6800 Conveyor Belt in Project Assembly of CV201 Belt – Southern Copper Cuajone*. Puno: National University of the Altiplano.
CEMA – Conveyor Equipment Manufacturers Association. (2007). *Belt Conveyors for Bulk Materials*. Florida, USA: Conveyor Equipment Manufacturers Association.
Danczyk, M., Meaclem, T., Mehdizad, M., Clarke, D., Galvosas, P., Fullard, L., & Hollanda, D. (2020). *Influence of Contact Parameters on Discrete Element Method (DEM) Simulations of Flow from a Hopper: Comparison with Magnetic Resonance Imaging (MRI) Measurements*. New Zealand.
Das, S. P., & Pal, M. C. (1987). *Stresses and Deformations of a Conveyor Power Pulley Shell under Exponential Belt Tensions*. India.
IDEA Statica. (December 1, 2020). *Idea Statica*. Retrieved from https://www.ideastatica.com/support-center/why-is-5-strain-limit-used-in-material-diagram-for-aisc
JET. (2019). *JET Painting Systems*. Lima: JET.
Lengua Huertas, C. A. (2016). *Study of T-Section Drive Pulleys for Conveyor Belts Classified between 800 and 2500 PIW*. Lima: Pontifical Catholic University of Peru (PUCP).
Manchego Llerena, R. (2017). *Course: Design of Machine Elements I – UNSA*. Arequipa.
Manchego Llerena, R. (2018). *Course: Design of Machine Elements II – UNSA*. Arequipa.
Manchego Llerena, R. (2019). *Course: Hydraulics and Pneumatics – UNSA*. Arequipa.
Martin Engineering. (2009). *Foundations*. Neponset, Illinois: Martin Engineering Company.
McCormac, J. C. (2002). *Design of Steel Structures – LRFD Method*. Mexico: Alfaomega.
Mott, R. L. (2006). *Machine Elements Design*. Mexico: Pearson Education.
Nicolas, A. S. (2002). *Hydraulics*.
Oviedo, J. (2019). *Course: Design of Material Handling Equipment – UNSA*. Arequipa.
Patel, T. R., Patel, R. R., & Joshi, P. S. (2014). *Conveyor Pulley Failure Analysis*. India.
Quadrant. (2011). *TIVAR88 High Performance Lining Solutions – Engineering Case Book*. USA: Quadrant.
R. Todd Swinder, P.E., D. Marti, A., Goldbeck, L. J., Marshall, D., & Strebel, M. G. (2009). *Foundations* (4th Edition). Neponset, Illinois, USA: Martin Engineering Company.
National Building Regulations of Peru. (2006). *Standard E.020*. Lima: Editora Peru.
National Building Regulations of Peru. (2018). *Standard E.030*. Lima: Editora Peru.
Research Council on Structural Connections. (2009). *Specification for Structural Joints Using High-Strength Bolts (RCSC)*. Chicago, Illinois: RCSC.
Samaniego, C. A. (2016). *Design of a Fine Ore Hopper with ASTM A36 Structural Steel Plates for Storing Polymetallic Mineral at 300 masl*.
Serrano, A. N. (2002). *Hydraulics*.
Sodimate Ibérica. (n.d.). *Sodimate Ibérica*. Retrieved from http://www.sodimateiberica.com
The European Union. (2006). *European Standard EN 1991-4 Eurocode 1 – Actions on Structures – Part 4: Silos and Tanks*. Brussels: CEN National Members.
TISUR. (2018). *Data Sheet – Copper Concentrate Properties*. Arequipa.
TISUR. (2019). *TISUR-150-041-INF-00002 Soil Study – Geotechnical Discipline*. Arequipa: TISUR.
Vasic, M., Stojanovic, B., & Blapojevic, M. (2019). *Failure Analysis of Idler Roller Bearings in Belt Conveyors*. Serbia.
Vinnakota, S. (2006). *Steel Structures: Behavior and LRFD*. Mexico: McGraw-Hill Interamericana.
Jenike, A. W. (1964). *Storage and Flow of Solids*. Salt Lake City, Utah: Utah Engineering Experiment Station.
Yardley, E. D., & Stace, L. R. (2014). *Design of Belt Conveyor Hardware (Idlers, Structure, Pulleys, Drives, Tensioning Devices, Transfer Points, and Belt Cleaning)*. USA.