DESIGN OF THE FIRST HIGH CAPACITY FLYINGBELT

Alberto Contin, Matteo Colombo
LEITNER SpA – Office Leini

ABSTRACT
Rogun Dam, 335-meters high, will be the tallest in the world and AGUDIO is part of this mega project in Tajikistan. A brand new Flyingbelt has been designed to be part of the conveyors line handling the material excavated and crushed from the job site. Rogun Flyingbelt will be the first high-capacity rope suspended conveyor, able to transport up 3 000 tons per hour over a single span of 650 metres. Moreover, it will be a reversible conveyor that will move the excavated material from the job site to the storage area in phase I of the project and from the storage to the site in phase II. This document will describe the challenges faced during the design of a reversible Flyingbelt and the solutions implemented.

1 INTRODUCTION

The Vakhsh River flows downstream cutting Tajikistan in two. Powerful icy waters swollen by the melted snows of the Pamir, the most impressive mountain range in Central Asia with peaks exceeding 7,000 meters. An incredible morphology that holds enormous hydroelectric potential.

The Rogun HPP (Hydropower Project), a $3.9 billion project with an expected duration of 13 years, will be carried out by WeBuild, the most prominent Italian construction company, which has signed an agreement with the OJSC "Rogun HPP" Open Joint-Stock Company (the government-controlled company coordinating the construction of the project). Works has been started with the construction of the dam, which first involves the detour of the Vakhsh River, which will be made to flow into two detour tunnels built underground, so as to dry out the foundations of the dam. This is a very complex operation that, because of the river's water flow, can only be completed in the winter months, when the mountains are snow-capped and the water level drops.

The dam is built of mixed material (2.7 million cubic meters of sand and stones with an impermeable clay core) and, viewed in section, is a large triangle, whose base measures 800 metres.

The Flyingbelt will play a strategic role in the material handling chain. It will cross a valley of 650 metres with one single flight, without supporting structures, and in Phase I of the project it will bring the excavated material from the site to the storage area and, in Phase II, from the storage area to the body of the dam.

Figure 1 – Map of Rogun site

WeBuild was already aware of the Flyingbelt technology because of the rope suspended belt installed in 2016 in one of the construction sites of the high-speed train in Genova, Italy. This Flyingbelt is only 300 meters long, but it saved time and money due to the fact that to cross the valley no fixed structure was needed to support the belt conveyor.

In the Rogun project, the Flyingbelt was again the best solution due to its advantages:

- Minimisation of CAPEX for conveyor chain: no steel structures needed to cross the valley
- High availability: already demonstrated in these years in Genova
- Customisation of the system: based on customer requirements, transfer points has been designed to be reversible and easily connected with upstream and downstream overland conveyors
- Integration of the suspended conveyor: it perfectly fits into a fully automated conveying chain
- Low maintenance cost: thanks to high quality components and the highest engineering standards, as confirmed in the other Flyingbelt already in operation.

The main challenges of the project were: the high capacity (3 000 tph), the long span to be covered (650 m) and the possibility of reversing the material transport direction.

Figure 2 – Reversible loading / offloading station

The solution proposed by AGUDIO is the result of a fully customised detailed study carried out by engineers specialised in several fields: rope design, belt analysis, mechanical design, constructability analysis. This study has been carried out following guidelines for material ropeways (OITAF book 8) and for conveyors (CEMA 7th), using software specifically developed by AGUDIO to simulate the static and dynamic behaviour of the system in different conditions (start-up, shut-down, normal operation, emergency stop, partial load operation).

Main technical data of Rogun Flyingbelt are the following:

- Material Aggregates
- Capacity tph 3 000
- Horizontal Length m 650
- Difference in Height m 30
- Belt width mm 1400
- Track ropes mm 4x65
- Hauling ropes mm 20
- Number of towers n° 0
- Motors nominal power (belt) kW 710

- Motors nominal power (maint) kW 30
- Speed of belt m/s 4

In the following paragraphs it is explained how ropes and belts have been calculated.

Figure 3 – Flyingbelt Rogun overview

2. ROPE LINE CALCULATION

This aerial conveyor is a traditional conveyor suspended on ropes anchored on both ends (loading/tail station and off-loading/head station).

The choice of track rope construction form, size and mechanical properties is the result of a detailed analysis performed in several conditions:

- minimum temperature (-10°C), loaded belt
- maximum temperature (+40°C), loaded belt
- minimum temperature (-10°C), empty belt
- maximum temperature (+40°C), empty belt
- loaded belt + max wind in service (250 Pa)

- empty belt + max wind out of service (1200 Pa)
- mounting conditions (bare ropes, line frames installation)

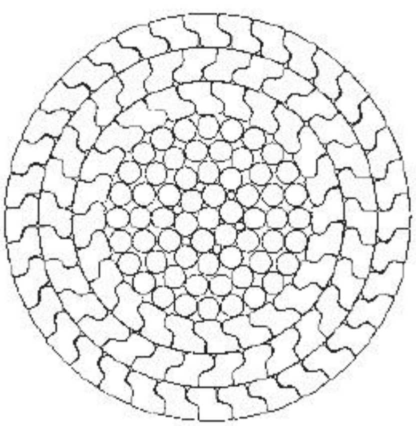
Even if the operating temperature range considered is 50°C, the ropeway guidelines suggest to take into consideration a minimum temperature range of 60°C.

Track ropes comply with the guidelines by international standards (1) about material transportation; according to them, the minimum track rope safety factor is:

- In service, without wind: ≥ 2.50
- Out of service, with wind (1200 Pa): ≥ 2.00
- In service, with wind (250 Pa): ≥ 2.50

(1) O.I.T.A.F., book no. 8-2, § 2.1.6.2, edition 2018, which states a minimum value of 2.50 on service. Concerning out of service + wind condition, the minimum admissible safety factor for material transportation is 2.00, proportionally derived from EN 12930:2015, § 7.4.2.

Track rope suitable for the installation is a locked coil one, with two layers of “Z” shaped wires, diameter 65mm; its main features are listed below:



Description	Locked coil rope with "Z" shaped wires	
Diameter	mm	65
Mass	kg/m	24.1
Section	mm^2	2827
Elastic Modulus	N/mm^2	160000
Minimum Breaking Force	kN	4734

Table 1 – Tracking ropes characteristics

The calculation of the anchored track ropes implies the definition of a “reference condition”, which is assumed as a steady condition with empty belt and minimum ambient temperature.

In this situation, an assigned tension is given to the track ropes, which is chosen in order to optimise the ropes behaviour and the running conditions.

Starting from these assumptions, the calculation procedure obtains all the line parameters in the “reference condition”, with simple closed formulas assumed as known.

In details, the procedure calculates the “section cumulative actual length”, that is the length assumed by the rope lying on a horizontal plane, without tension and without weight.

For each further load condition, different for temperature or for live load on the belt, the procedure iterates the calculation several times, varying the track rope tension, ending the calculation when the new values of the “section cumulative actual length” equal the original reference ones.

At the end of the calculation the safety factor must be higher than the one indicated in the guidelines (OITAF Book 8)

For the purpose of line calculation, the full system is treated as a single anchored rope with the following assumption:

- equivalent rope tension equals the sum of track ropes
- equivalent rope weight equals the sum of track ropes, suspended frames, rollers and miscellanea, carry and return side of the belt, bulk load on the belt

The weight of the suspended frames and rollers is applied as a uniform load distributed along the track ropes; live load may be different in different spans, according to the load condition investigated.

GENERAL PARAMETERS			
		one rope	cumulative
diameter	mm	65.00	
track ropes weight	N/m	236	945
track ropes cross section	mm2	2827	11308
track ropes elastic modulus	N/mm2		160000
track ropes calculated strength	kN	4734	18936
track ropes breaking load	kN	4734	18936
track ropes termic			0.0000120
Reference tension value (total)	N		1816000
track rope sections number			4
belt weight (going & return)	N/m		569
frame weight	N/m		1139
cumulative steady load	N/m		2084
mobile load with empty belt	N/m		569
mobile load with loaded belt	N/m		2613
accidental load	N/m		0
wind horizontal load - Out of service	N/m		2514
wind horizontal load – In service	N/m		524

Table 2 – Flyingbelt Rogun general parameters (input data)

Safety factors are calculated in all the following conditions:

- Design condition 1: loaded belt, minimum temperature
- Design condition 2: loaded belt, maximum temperature
- Design condition 3: empty belt, minimum temperature
- Design condition 4: empty belt, maximum temperature
- Design condition 5a: bare ropes, minimum temperature
- Design condition 5b: bare ropes, maximum temperature
- Design condition 6a: ropes + frames, minimum temperature
- Design condition 6b: ropes + frames, maximum temperature
- Design condition 7a: wind out of service, minimum temperature
- Design condition 7b: wind out of service, maximum temperature
- Design condition 8a: wind on service, minimum temperature
- Design condition 8b: wind on service, maximum temperature

					rope load	fixed load	mobile	extra	total
RUNNING CONDITION N°		**1**			**N/m**	**N/m**	**load**	**load**	**load**
LOADED BELT - MINIMUM TEMPERATURE					**945**	**1139**	**2613**	0	**4696**
span number/vertex number						**ASC - AC**			
live load factor						1.00			
mobile load						2612.73			
total load						4696.24			
track rope tension at first span end					N	6980454			
track rope tension at last span end					N	7123125			
belt tension at first span end					N	1			
belt tension at last span end					N	79376			
rope inclination at first span end					rad	-0.1547			
rope inclination at last span end					rad	0.2509			
average track rope tension					N	7012101			
cumulative horizontal tension					N	6898601			
span vertical sag					m	31.16			
added span length					m	4.27			
track rope elastic elongation					m	2.36			
track rope actual length					m	607.46			
section cumulative actual length					m	607.46			

Table 3 – Analysis of ropes in minimum temperature conditions and loaded belt

OVERALL TENSIONS					
TRACK ROPE MAX T			**N**	**7123125**	
TRACK ROPE SAFETY				**2.658**	**OK**
TRACK ROPE MAX T - WIND 7			**N**	**5829182**	
TRACK ROPE SAFETY - WIND 7			*1200*	**3.248**	**OK**
TRACK ROPE MAX T - WIND 8			**N**	**7158089**	
TRACK ROPE SAFETY - WIND 8			*250*	**2.645**	**OK**

Table 4 – Summary of tensions and safety factors

3.HAUL ROPE CALCULATION

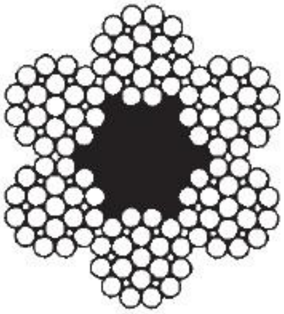
Haul rope for maintenance vehicle is related to an evacuation rope.

It complies with the guidelines by European standard EN12927:2019 for people transportation; according to it, the minimum haul rope safety factor is ≥ 2.90 (reference: §8.2).

Figure 4 – Maintenance vehicle

Haul rope is closed in a spliced loop; the vehicle is fixed to the rope by means of a bolted clamp.

Haul rope is a Redmont 6k19, diameter 20mm; its main features are listed below:



Description	Redmont 6k19 (6 x k19 S - SFC)	
Diameter	[mm]	20
Mass	[kg/m]	1.60
Section	[mm^2]	180
Elasctic Modulus	[N/mm^2]	120000
Minimum Breaking Force	[kN]	318

Table 5 – Hauling ropes characteristics

Details of haul rope dimensioning are reported in the following table:

Maximum tension	kN	52.30
Breaking load	kN	318.00
Safety factor		**6.08**
Max tension at the winch	kN	52.30
Min tension at the winch	kN	50.20

Table 6 – Analysis of hauling rope in nominal conditions

4. BELT CONVEYOR LINE CALCULATION

The choice of the belt conveyor is the result of static analysis performed in six different conditions:

- minimum temperature (-10°C), loaded belt

- maximum temperature (40°C), loaded belt
- minimum temperature (-10°C), empty belt
- maximum temperature (40°C), empty belt
- worst starting condition (with only inclined section loaded and minimum temperature)
- worst breaking condition (with only declined section loaded and maximum temperature)

Since the conveyor is reversible, all calculations are made both for the main direction and for the reverse one.

The layout of the track ropes is set as input for the belt calculation; the rope configuration corresponding to maximum temperature and loaded belt is prudently considered for all conditions.

The belt complies with the limits imposed by the manufacturer (e.g. safety factor, minimum radius in vertical convex curves, transition distances, etc), in detail:

- average running (loaded belt or empty belt) safety factor: ≥ 6.67
- average transient phases (starting/stopping) safety factor: ≥ 4.60
- local running and local transient phases safety factor: ≥ 4.00

The idlers on the carry side are six-roll garlands with a 2.0m spacing, while on the return side they are two-roll garlands, with 6.0m spacing (Fig. 5).

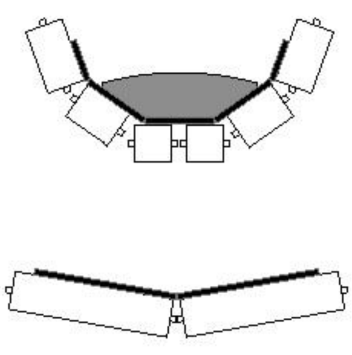


Figure 5 – Rollers

On the ground sections close to both end stations (loading and offloading stations), the spacing of the garlands on the carry side is reduced to 1.0m, and on the return side, a single-roll fixed frame idler replace return side's garlands, in order to enable a vertical convex curve with a radius of 90m.

Belt line calculation is performed according to CEMA 7th – Universal method, using the software Belt Analyst™ version 18.0.3.0, written by Overland Conveyor Company Inc.

The "base case" is loaded belt at minimum temperature (-10°C).

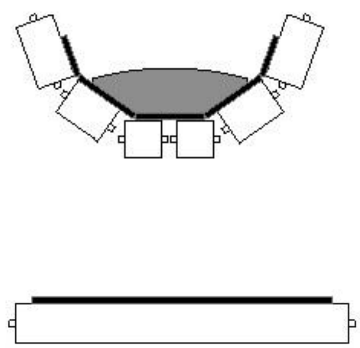


Figure 6 – Traditional conveyor rollers

The belt of the aerial conveyor is computed according to the following data:

- Load capacity: 3000 tph
- Belt speed: 4.0 m/s
- Belt width: 1400 mm
- Bulk density: 1700 kg/m3
- Surcharge angle: 22°
- Maximum lump size: 400 mm

The resulting filling factor (for 70° troughing angle) and edge distance are respectively 47% and 269 mm.

Drive pulley is installed in head station (with reference to main direction); wrap angle is 180° and it has rubber (diamond) lagging, in order to ensure adherence.

Belt tensioning is of fixed type: in fact the take-up pulley is mounted on a sledge, which is anchored on a couple of guides by means of pins.

Thermal elongation of the belt is taken into account in line calculation, since it affects the tension inside the belt. On the other side, permanent elongation can be recovered by shifting the position of the take-up along the guides.

Scheme of the belt line, with reference to main direction

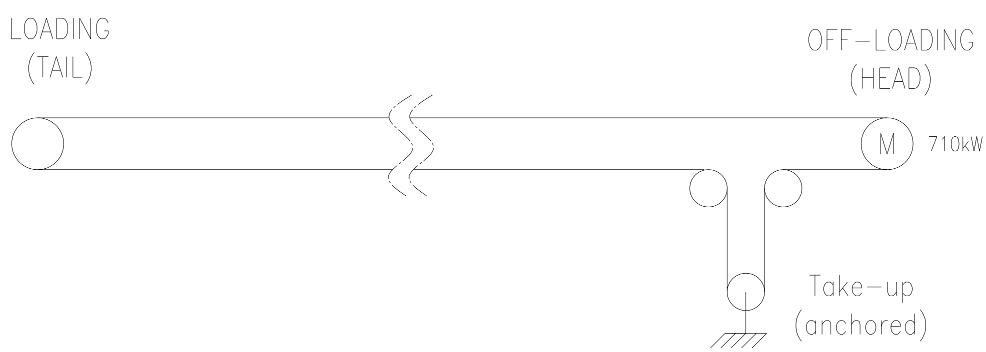


Figure 7 – Scheme of the belt line

The belt is computed considering 60s start time, while the installed brake effort allows stopping the belt in 25s in the worst loading condition. All garlands have Ø133mm steel rolls and Idler to belt friction coefficient is 0.50

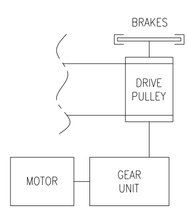
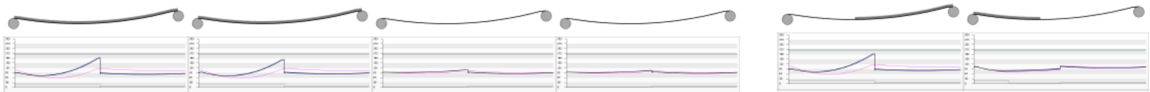
	FB Rogun - main direction
PROFILE	
	
Horizontal length [m]	647
Vertical lift [m]	30
BELT	
Type	Metaltrans M 1400 - 6+3
Width [mm]	1400
Speed [m/s]	4.0
TAKE-UP	
Location	Head (with rerefence to main direction)
Type	anchored
Reference weight [kg]	26000 (at -10°C, with empty belt)
Take-up travel due to:	
- belt dynamics [m]:	0.00
- permanent stretch [m]:	2.27
Total take-up stroke [m]	2.27
DRIVES	
Power consumption	
Running power, loaded belt:	
- at -10°C [kW]	624
- at 40°C [kW]	531
Running power, empty belt:	
- at -10°C [kW]	140
- at 40°C [kW]	101
Starting power:	
- peak in worst condition [kW]	750
Head (reference: main direction)	
Number of drive pulleys	1
Number of motors	1
Nameplate power [kW]	710
Installed brake torque [Nm]	17300
Winch scheme	

Table 7 – Power consumption in nominal conditions

Case Summary



Case Name	Loaded belt, Tmin (Base)	Loaded belt, Tmax	Empty belt, Tmin	Empty belt, Tmax	Inclines loaded	Declines loaded
Load (mtph)	**3000**	**3000**	**3000**	**3000**	**3000**	**3000**
Percent Loaded	47	47	47	47	47	47
Ambient Temperature (° C)	**-10.0**	**40.0**	**-10.0**	**40.0**	**-10.0**	**40.0**
Total Friction Force (kN)	57.1	36.1	18.1	9.4	41.0	13.6
Lift Force (kN)	61.6	61.6	0.0	0.0	104.6	-43.0
Misc Drag (kN)	20.6	20.7	13.1	13.1	13.0	17.0
Equivalent Friction Coefficient	0.0316	0.0200	0.0382	0.0198	0.0323	0.0134
Description	Earth Wet with Clay	Earth Wet with Clay	Earth Wet with Clay	Earth Wet with Clay	Earth Wet with Clay	Earth Wet with Clay
Material Density (kg/m³)	**1700**	**1700**	**1700**	**1700**	**1700**	**1700**
Surcharge Angle (degrees)	**22.0**	**22.0**	**22.0**	**22.0**	**22.0**	**22.0**
Lump Size (mm)	**400**	**400**	**400**	**400**	**400**	**400**
Total Nameplate (kW)	710	710	710	710	710	710
Percent Running Power	87.2	74.2	19.5	14.1	99.3	-6.2
Start Time (sec)	60.0	60.0	60.0	60.0	60.0	60.0
Stopping Belt Travel (m)	11.46	12.96	13.57	15.42	8.14	49.99
Stopping Discharge (kg)	2387.74	2699.20	0.00	0.00	1696.46	0.00
Rating (N/mm)	210	210	210	210	210	210
Average Running S.F.	7.7	8.1	12.7	13.2	7.4	13.0
Average Starting S.F.	7.4	7.9	12.6	13.1	7.2	13.3
Average Stopping S.F.	11.8	11.7	13.4	13.3	11.3	12.4
Local Running S.F.	6.0	6.2	7.3	7.3	5.8	6.9
Local Starting S.F.	5.8	6.1	7.3	7.3	5.7	7.0
Local Stopping S.F.	6.8	6.8	7.3	7.3	7.4	6.9
Splice Running S.F.	2.7	2.8	3.3	3.3	2.6	3.1
Splice Starting S.F.	2.6	2.7	3.3	3.3	2.5	3.1
Splice Stopping S.F.	3.1	3.1	3.3	3.3	3.3	3.1
Normal TU Tension kN	121	127	127	131	113	145
Requirement	Run Slip	Run Slip	Run Slip	Run Slip	Accel Slip	Run Slip

Table 8 – Belt analysis in different conditions

The same calculation has been done in reverse conditions (Phase II):

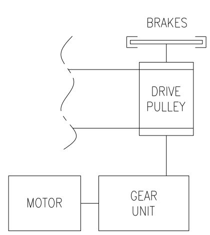
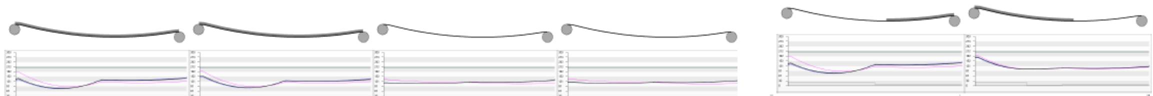
	FB Rogun - reverse direction
PROFILE	
	
Horizontal length [m]	647
Vertical lift [m]	-30
BELT	
Type	Metaltrans M 1400 - 6+3
Width [mm]	1400
Speed [m/s]	4.0
TAKE-UP	
Location	Head (with rerefence to main direction)
Type	anchored
Reference weight [kg]	37000 (at -10°C, with empty belt)
Take-up travel due to:	
- belt dynamics [m]:	0.00
- permanent stretch [m]:	2.27
Total take-up stroke [m]	2.27
DRIVES	
Power consumption	
Running power, loaded belt:	
- at -10°C [kW]	84
- at 40°C [kW]	-52
Running power, empty belt:	
- at -10°C [kW]	149
- at 40°C [kW]	109
Starting power:	
- peak in worst condition [kW]	447
Head (reference: main direction)	
Number of drive pulleys	1
Number of motors	1
Nameplate power [kW]	710
Installed brake torque [Nm]	43000
Winch scheme	

Table 9 – Belt analysis in different conditions

Case Summary



Case Name	Loaded belt, Tmin (Base)	Loaded belt, Tmax	Empty belt, Tmin	Empty belt, Tmax	Inclines loaded	Declines loaded
Load (mtph)	**3000**	**3000**	**3000**	**3000**	**3000**	**3000**
Percent Loaded	47	47	47	47	47	47
Ambient Temperature (° C)	**-10.0**	**40.0**	**-10.0**	**40.0**	**-10.0**	**40.0**
Total Friction Force (kN)	57.0	24.1	18.1	9.4	33.8	16.7
Lift Force (kN)	-61.6	-61.6	0.0	0.0	43.0	-104.6
Misc Drag (kN)	23.4	23.0	15.1	15.0	16.1	18.2
Equivalent Friction Coefficient	0.0316	0.0133	0.0382	0.0198	0.0334	0.0132
Description	Earth Wet with Clay	Earth Wet with Clay	Earth Wet with Clay	Earth Wet with Clay	Earth Wet with Clay	Earth Wet with Clay
Material Density (kg/m³)	**1700**	**1700**	**1700**	**1700**	**1700**	**1700**
Surcharge Angle (degrees)	**22.0**	**22.0**	**22.0**	**22.0**	**22.0**	**22.0**
Lump Size (mm)	**400**	**400**	**400**	**400**	**400**	**400**
Total Nameplate (kW)	710	710	710	710	710	710
Percent Running Power	11.7	-7.4	20.8	15.3	58.1	-35.3
Start Time (sec)	60.0	60.0	60.0	60.0	60.0	60.0
Stopping Belt Travel (m)	17.05	23.54	7.20	7.70	7.25	49.94
Stopping Discharge (kg)	3551.96	4903.62	0.00	0.00	1510.68	0.00
Rating (N/mm)	210	210	210	210	210	210
Average Running S.F.	9.6	9.0	10.4	10.6	9.2	7.9
Average Starting S.F.	9.4	9.3	10.4	10.5	9.1	8.1
Average Stopping S.F.	7.7	7.5	10.5	10.3	10.3	7.5
Local Running S.F.	6.7	6.6	7.0	7.1	6.6	6.0
Local Starting S.F.	6.7	6.7	7.0	7.1	6.5	6.1
Local Stopping S.F.	5.9	5.8	7.0	7.1	7.0	5.7
Splice Running S.F.	3.0	2.9	3.2	3.2	3.0	2.7
Splice Starting S.F.	3.0	3.0	3.2	3.2	2.9	2.7
Splice Stopping S.F.	2.6	2.6	3.2	3.2	3.2	2.6
Normal TU Tension kN	198	189	181	178	206	167
Requirement	Run Sag	Run Sag	Run Sag	Run Sag	Accel Slip	Run Sag

Table 10 – Belt analysis in different conditions

5. CHUTE CALCULATION

Transfer chute have been designed internally using Bulk Flow Analyst software, starting from the following assumptions:

- Material type: generic excavation aggregate
- Minimum density: 1700 kg/m3
- Maximum particle size: 400 mm
- Water content: ≤ 4% the material is to be considered dry and non-packing
- Particle distribution as per following:

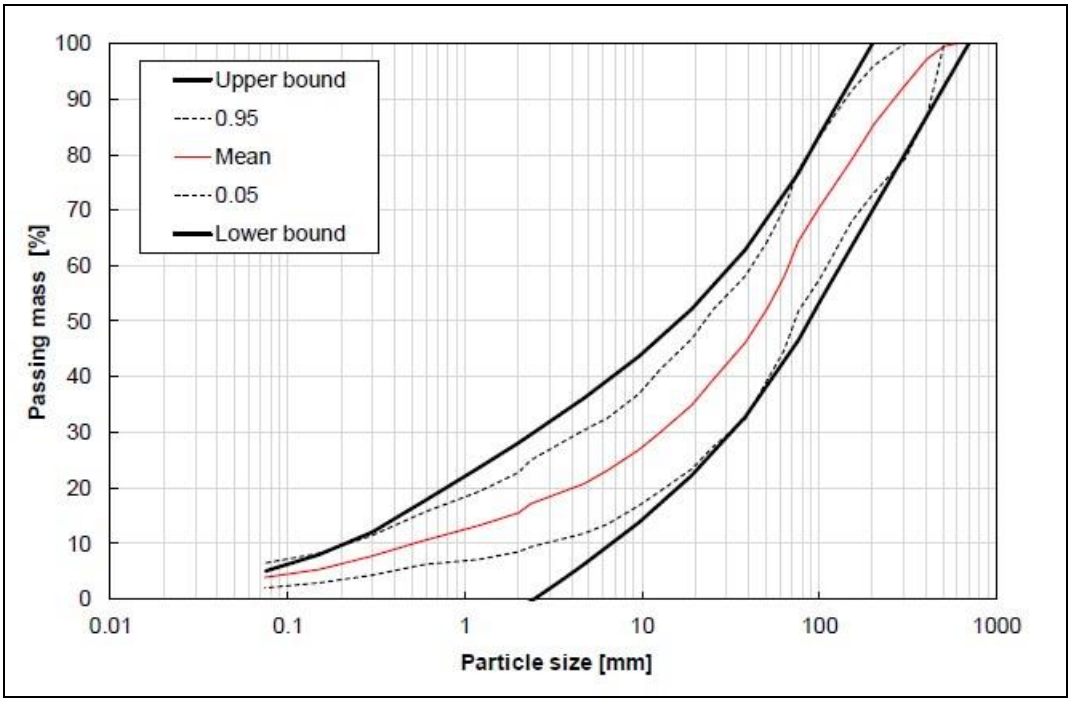


Figure 8 – Particle size distribution

Based on the particle distribution a model of the material to be conveyed is created in Bulk Flow Analyst and the following verification has been done:

- Verification of trajectory of particles to avoid area of stagnation that might cause clogging of the chute
- Verification of the speed of the material at the exit of the chute in order to be as much as possible aligned with the speed of the conveyor belt

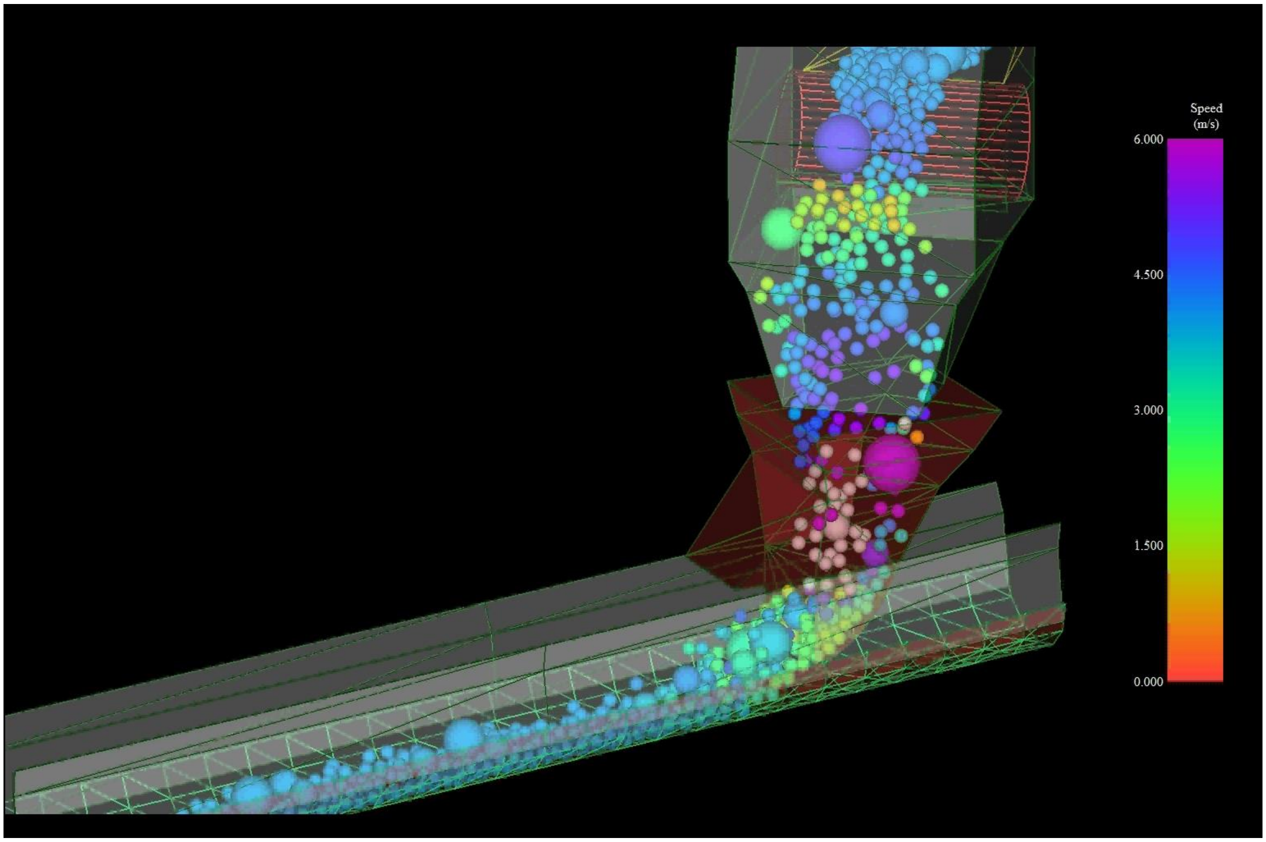


Figure 9 – Chute DEM flow simulation

- Verification of the impact forces to properly size the chute

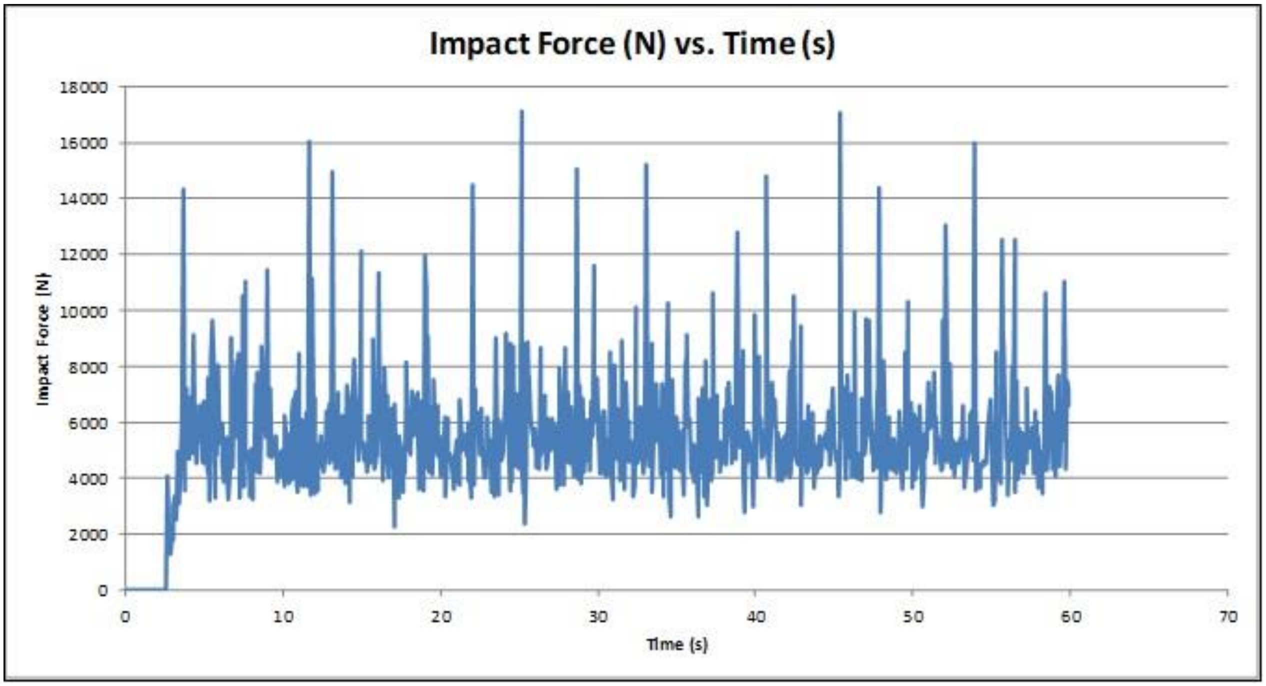


Figure 10 – Impact forces on the chute

6. CONCLUSION

Although this Flyingbelt will be the first high capacity one, it is still far from the limits of the technology, in fact to move 3000 tph of material over a single span of 650 meters only four medium size track ropes will be used (65 mm).

The possibility of increasing the belt speed, using larger belts, using larger ropes, and even the possibility of increasing the number of ropes to 6 or even 8 leaves room for the possibility of designing Flyingbelts of even higher capacities suitable for use not only in the cement production sector but also in the mining sector where the required conveying capacities are often several thousand tons.

REFERENCES

Standards:

[1] O.I.T.A.F. (International Organizations for Transportation by Rope) - BOOK 8 – edition 2010: recommendations for the construction and operation of material handling unidirectional and reversible ropeway installations, cable cranes and material handling funiculars (www.oitaf.org).

[2] CEMA Belt Book "Belt Conveyors for Bulk Materials" 7th edition

ABOUT THE AUTHORS

ALBERTO CONTIN

Alberto Contin graduated in Mechanical Engineering at Politecnico di Torino. He started his work at Agudio-Leitner in 1997 as mechanical designer in the technical office where he has been involved in different type of cableways. In 2008 he started focusing on material transportation and he developed the recent installations of cablecranes, material ropeways and Flyingbelt. Today he is the senior product manager for material handling under the brand Agudio.

Alberto Contin

LEITNER SpA – Office Leini

Senior Product Manager

Ph +39 011 997 33 55

alberto.contin@agudio.com

www.agudio.com

MATTEO COLOMBO

Matteo Mario Colombo has a degree in Civil Engineering – Transportation and a degree in Aerospace Engineering, from Politecnico di Milano. He works as Project Engineer at the technical office of Leitner, designing ropeway installations for both people and material transportation.

Matteo Colombo

LEITNER SpA – Office Leini

Senior Product Manager

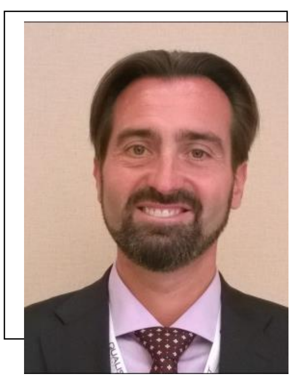
Ph. +39 011 069 12 94

matteo.colombo@leitner.com

www.agudio.com

ABOUT THE PRESENTER

STEFANO CATTANEO



Stefano Cattaneo has a degree in mechanical engineering from Politecnico di Milano and an MBA from MIP business school. He started his career in Foster Wheeler as an engineer and then moved into management positions in leading engineering companies.

Today he is Global Sales and Marketing Manager for rope-hauled material transportation systems in Agudio-Leitner".

Stefano Cattaneo

LEITNER SpA – Office Leini

Global Sales and Marketing Manager

Ph +39 011 997 33 55

stefano.cattaneo@agudio.com

www.agudio.com