DESIGN CONSIDERATIONS ON CAPACITY UPGRADE OF 6 KM DOWNHILL CONVEYOR SYSTEM

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ABSTRACT

The paper focuses on the drive upgrade of two downhill regenerative conveyors running in one of the existing projects of NMDC Ltd. (Bailadila Iron Ore Mine, Bacheli, Chhattisgarh State, India) for conveying additional load. A technical audit was conducted and it was recommended to replace the old drive and braking system with state of the art variable speed drives and a soft braking system on the slow speed side. This would enable the conveyors to be upgraded to handle a design load of 3 000 tph by increasing the belt speed up to 4 m/s while keeping all the conveyor structures, belting and other components the same. Accordingly, a study was undertaken to recommend minimum design parameters for those conveyors and a report compiled listing the considerations and requirements.

The paper discusses the design considerations and engineering solutions recommended for the proposed capacity upgrade of the selected downhill regenerative conveyors. A comprehensive brief including design criteria; power demand/regeneration for various loading cases; selection of drive components (motors, variable speed drives, gearboxes, low speed side hydraulic disc brakes having a soft braking option; couplings; pulleys etc.); static and dynamic behaviour, suitability of existing belting; take-up tension, additional safety features; drive house sizing and handling facilities; and discharge chute modification requirements is presented.

Key words: upgrade, downhill regenerative conveyor, variable speed drive, soft braking and disc brake.

1. BRIEF OF DOWNHILL CONVEYOR SYSTEM

1.1 The downhill conveyor system (DCS) of Bld. 5, Bacheli Complex was commissioned in 1977 and transports crushed iron ore from hilltop to foothill, crossing two hills.

1.2 The DCS is 6 km long and consists of conveyors 24, 27, 28, 29, 31, 32 including traveling tripper – 33 between the stockpiles. The upgrade involves verification of all these conveyors in the stream for handling a design load of 3 000 tph. However, the paper focuses on conveyors 28 and 29 considering their critical nature and the advanced engineering involved.

1.3 Figure 1 shows the equipment and facilities of the downhill conveyor system. Key profiles (not to scale) of conveyors 28 and 29 are also shown for reference (distances and levels are given in metres).

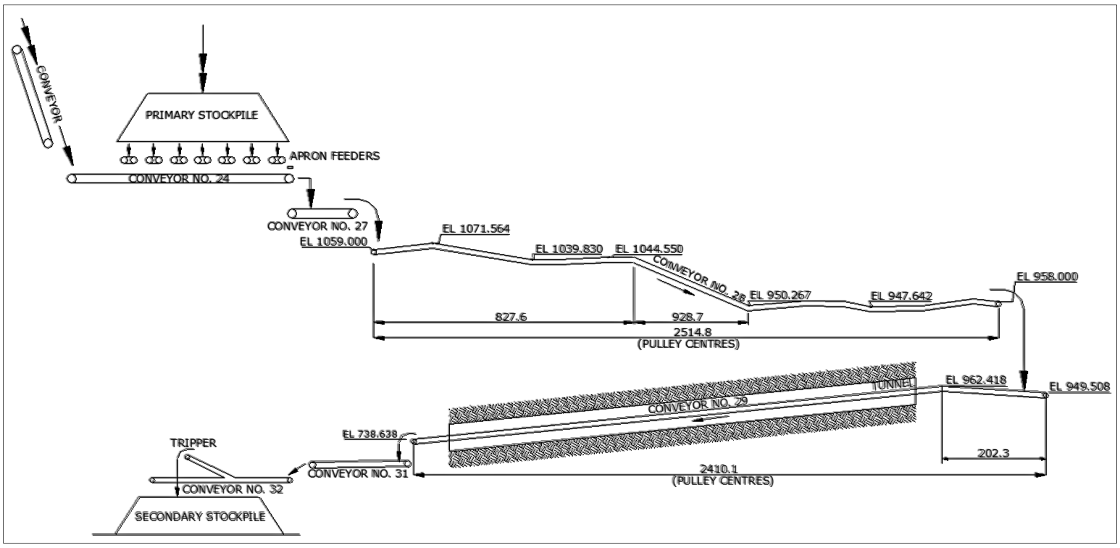


Figure 1. Equipment and facilities at downhill conveyor system.

2. PARAMETERS OF DOWNHILL CONVEYORS 28 AND 29

2.1 Each of two critical regenerative downhill conveyors 28 and 29 are about 2.5 km long with steel cord belting ST 2250 and ST 5000 respectively. Conveyor 29 runs through a 2.1 km long tunnel.

2.2 The existing drive and braking system (1992) of these two conveyors is of 3.3 kV slip ring induction motor and DC injection electrical braking system with hydraulic disc brakes on the high speed side having PLC based closed loop control. For stable operation, feed to conveyor is restricted to 2 100 tph at 3 m/s due to braking limitation and non-availability of old equipment spares.

2.3 A brief specification of these two existing downhill conveyors of the DCS is given below in Table 1 for reference.

Parameter	Conveyor 28	Conveyor 29
Belt Width	1050 mm	1000 mm
Horizontal Length	2.5 km	2.4 km
Drop [-] (approx.)	(-) 101 m	(-) 211 m
Max. Slope (approx)	10 Deg. (down)	6 Deg. (down)
Belt Speed	3 m/s	3 m/s
Drive Motor *(3.3 kV, 50 Hz, 1000 RPM, 3 phase, slip ring induction motor)*	450 kW – 1 No. at tail end 150 kW – 1 No. at head end	450 kW – 3 Nos. at tail end 150 kW – 1 No. at head end
Braking System *(limited to max. 2100 TPH)*	DC injection electrical braking system and a mechanical disc brake on high speed side.	
Special Features	**(a) Belt turn-over device (b) Motorised take-up winch with load** cell for automatic belt tensioning and correction.	

Table 1. Brief specification of downhill conveyors 28 and 29.

3. NEW OVERLAND CONVEYOR SYSTEM – NOT A VIABLE OPTION

3.1 The option of laying a new parallel overland conveyor system was studied as an alternative solution since the existing system had completed 40 years of successful service. However, the following limitations ruled out a new overland conveyor system:

- Length of downhill conveyor system increases by 2.6 km
- Regenerative power of about 1 MW would be lost as overland conveyors have to rise and travel a long way to clear the hillocks
- The number of conveyors would increase resulting in additional transfer houses, drive systems, pulleys etc., increasing operational and maintenance activities
- High legged trestles up to 74 m (approximate) may be needed to support the conveyor gallery, which makes the system complicated
- The overland conveyor would pass through an active mining area of another operating mine
- Higher magnitude of capital investment.

3.2 In view of the above, the capacity upgrade of the existing downhill conveyor system was considered to be a feasible option for implementation.

4. DESIGN CRITERIA

4.1 The following are the properties of material conveyed and environmental conditions considered for design verification of the downhill conveyors:

Material conveyed	: Steel grey haematite iron ore, crushed
Design capacity	: 3 000 tph
Bulk density	: 2 200 to 2 800 kg/m^3
Surcharge angle	: 20°
Maximum lump size	: 150 mm
Temperature range	: 10 to 45 °C

Conveyor runs in the existing structure and path.

5. BELT SPEED, CARRYING CAPACITY AND FILL FACTOR

5.1 The maximum capacity possible with the existing speed is about 2 400 tph and 2 300 tph for conveyor 28 and 29 respectively. Therefore, in line with the audit report recommendations it was decided to achieve the design capacity by increasing the speed.

5.2 Accordingly, speed vs carrying capacity is worked out based on the CEMA method for arriving at optimum speed and a graph is plotted in Figure 2. Restricting the fill factor level up to 80% is considered as a safe limit on carrying capacities. It can be seen that the carrying capacities of conveyors 28 and 29 are about 3 200 tph and 3 000 tph respectively at the belt speed of 4 m/s.

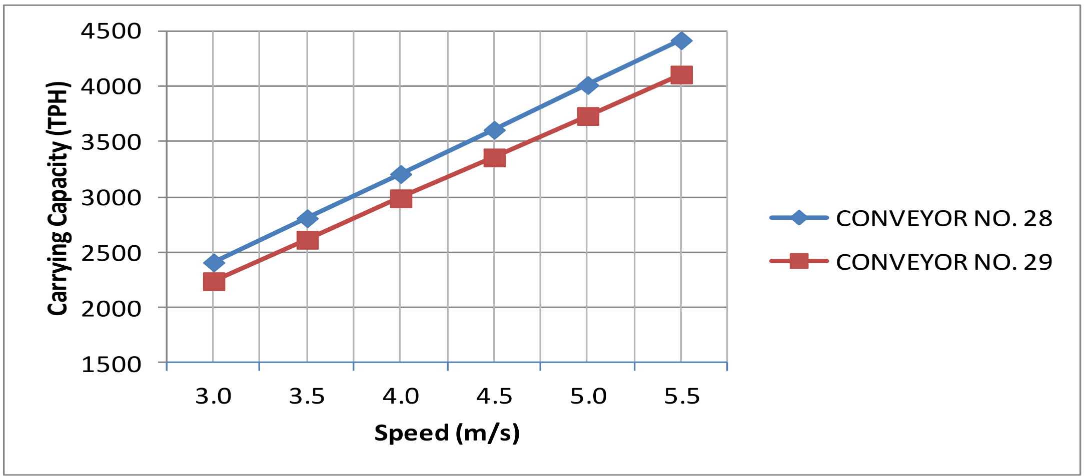


Figure 2. Speed vs carrying capacity at 80% fill factor.

5.3 Further, operating these conveyors at 4 m/s speed is considered to be in comfortable range as NMDC is operating downhill regenerative conveyors, which are running at 4 m/s and more. Considering the above and NMDC's experience, speed of the conveyor is selected as 4 m/s for carrying a load of 3 000 tph (Design).

6. CONVEYOR ANALYSIS

The belt conveyors in question were studied and analysed for the following loading conditions:

- Fully loaded (FL) belt at 3 000 tph load at 4 m/s belt speed
- Empty belt at 4 m/s belt speed
- All decline sections loaded (DL) at 3 000 tph load at 4 m/s belt speed
- All incline sections loaded (IL) at 3 000 tph at 4 m/s belt speed.

The conveyors were studied for the above listed loading conditions with various friction factor values. The frictional factor values are hypothetical idler friction factor as per DIN standard and predicted based on existing conveyor characteristics. A reasonable check on the friction factor based on the power demand/generation values obtained during the conveyor audit was carried out. The friction factor effected by the conveyor design software was also compared. Further, the calculations were verified with software results. Ambient temperature and motor efficiency was also considered while selecting the friction factor.

For a conveyor with the following characteristics (Table 2), the standard value of friction factors should range from 0.01 to 0.02 as per DIN standard.

Characteristic	Value assumed
Internal friction of material conveyed	Medium to high
Belt conveyor alignment	Medium
Operating conditions	Medium *(dusty environment)*
Idler diameter	152.4 mm
Carrying idler spacing	1 m
Return idler spacing	2.5 m
Belt speed	4 m/s
Troughing angle	35 deg.
Ambient temperature	10 to 45 °C

Table 2. Characteristics of conveyor.

As per the technical audit conducted on the conveyors during 2006, the recorded values of power demand/regeneration at different loading conditions were noted and compared with theoretical calculations. It was noted that the friction factor during normal running condition varied from 0.0115 to 0.014.

The design report recently commissioned on a similar downhill conveyor considered a DIN factor of 0.012 for fully loaded and decline loaded conditions and 0.022 for empty and incline loaded conditions.

The friction factor applied by the software while analysing the conveyor as per CEMA (7^{th} edition) method is given in Table 3 for reference.

Load case	Friction factor assumed by software for conveyor 28	Friction factor assumed by software for conveyor 29
FL (3 000 tph)	0.0129	0.0127
Empty	0.0188	0.0180
DL (3 000 tph)	0.0128	0.0127
IL (3 000 tph)	0.0203	0.0182

Table 3. Load case and friction factor applied by software.

Considering the above, these conveyors were studied for the following combinations of loading conditions and friction factors:

Loading condition	Friction factor used
FL (3 000 TPH)	0.012
Empty	0.023
DL (3 000 TPH)	0.012
IL (3 000 TPH)	0.023

Table 4. Load case and friction factor considered for analysis.

The above conveyor loading conditions were analysed for the following operational conditions:

- Static analysis (at 4 m/s speed)
- Normal motor stop, dynamic analysis (braking by variable frequency drives and mechanical brakes are applied once the conveyor is stopped) and proportional stop, dynamic analysis (complete braking by disc brakes)
- Operational start and dynamic analysis; the drives are controlled to accelerate the belt in a smooth manner following the predetermined 'S' curve.

7. ROUTE AND PROFILE OF CONVEYORS 28 AND 29

7.1 The conveyors continue to run in the existing corridor and alignment. Tail end extension of 17 m (approx.) and 23 m (approx.) is planned for conveyors 28 and 29 respectively for installing a new drive system.

7.2 Conveyor 28 travels about 2.5 km with a drop in elevation of 101 m from the receiving point (conveyor 27 discharge chute) to discharge point (tail end of conveyor 29). Along the route, the conveyor negotiates 19 vertical curves. The elevation of conveyor 28 is given below:

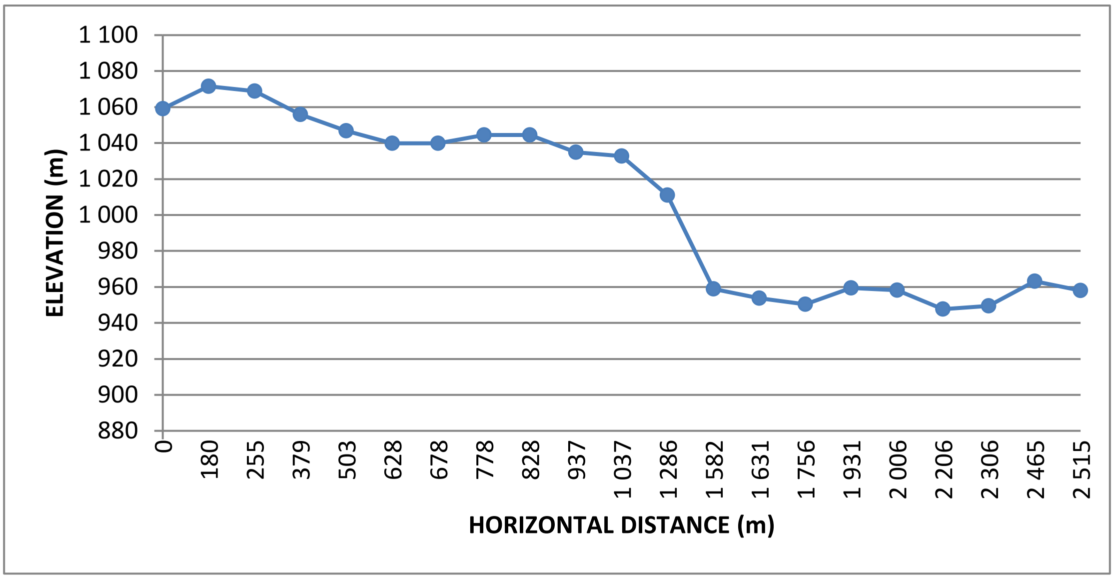


Figure 3. Elevation of conveyor 28.

7.3 Conveyor 29 travels about 2.4 km with a drop in elevation of 210.9 m from the receiving point (conveyor 28 discharge chute) to discharge point (tail end of conveyor 31). Along the route, the conveyor negotiates one vertical curve. The conveyor travels in a tunnel of about 2.1 km length. The elevation of conveyor 29 is given below:

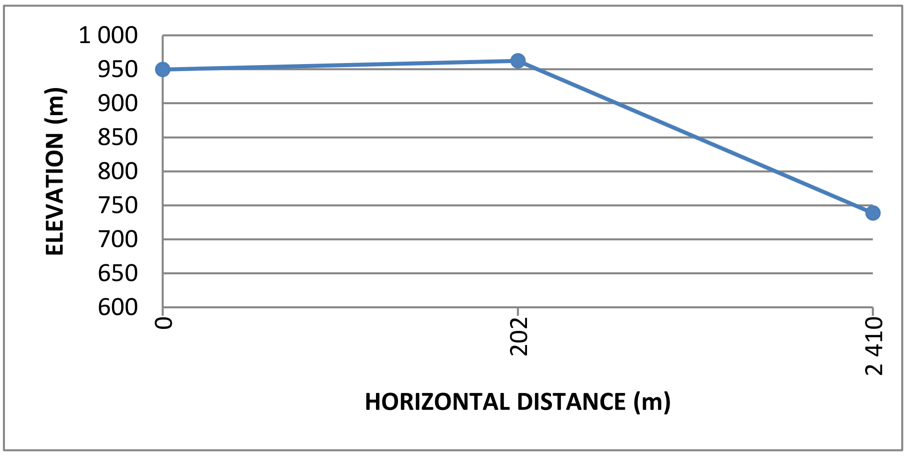


Figure 4. Elevation of conveyor 29.

7.4 The drive system of both the conveyors are located in their respective tail ends. Conveyor 28 houses one number 450 kW drive at the tail end and one number 150 kW drive at the head end. Conveyor 29 houses three number 450 kW drives at the tail end and one number 150 kW drive at the head end. For both the conveyors, the load receiving point is located after the tail pulley. The material is fed through a discharge chute.

7.5 The return side of both conveyors include belt turn-over at head and tail ends. Motorised winch take-up with load cell for automatic belt tensioning and correction is provided near the head end of both conveyors.

8. MOTOR POWER

8.1 Power demand/regeneration is calculated to select the suitable capacity drive motor(s). Calculations are performed using basic formulae manually and verified using software program for the CEMA 7th method and the DIN method.

8.2 Power demand/regeneration is worked out by summing-up power required to overcome the various resistances produced by the conveyor system. The method used for manual calculation follows the basic principles of conveyor design as presented below.

$P = P1 + P2 + P3 + P4.kW$ 1

Power consumed by all moving parts of the conveyor.

$P1 = (C\ R\ L/367)\ (3.6\ A\ v).kW$ 2

Power required for moving the load horizontally.

$P2 = (C\ R\ L/367)\ (Q).kW$ 3

Power required for lifting/lowering the material.

$P3 = Q\ H\ /367.kW$ 4

Power consumed by conveyor accessories.

$P4 = P_{sk} + P_{sc}.kW$ 5

Where

C – Length correction factor
R – Idler friction factor
L – Conveyor horizontal centre to centre distance, m
A – Mass of moving parts, kg/m
v – Belt speed, m/s
Q – Conveyor carrying capacity, t/hr
H – Lifting/lowering of material, m
P_{sk} – Power for skirt board, kW
P_{sc} – Power for scrappers, kW

For the sake of simplicity, power required for accelerating material in the feed zone is not considered, as this does not contribute significantly to the total power requirement and for regenerative conveyors, P4 is considered as zero.

8.3 Results of calculations performed for power demand/regeneration of conveyor 28 are tabulated below:

Loading condition	Power demand (+) / Regeneration (-) [kW]			
	Manual calculation	CEMA 7th Method *(Software results)*	CEMA 7th Method *(User friction factor)*	DIN method *(Software results)*
FL	(-) 425	(-) 386	(-) 413	(-) 371
Empty	(+) 285	(+) 224	(+) 270	(+) 237
DL	(-) 850	(-) 830	(-) 849	(-) 815
IL	(+) 788	(+) 732	(+) 761	(+) 725

Table 5. Power demand/regeneration of conveyor 28.

8.4 Results of calculations performed for power demand/regeneration of conveyor 29 are tabulated below:

Loading condition	Power demand (+) / Regeneration (-) [kW]			
	Manual calculation	CEMA 7th Method *(Software results)*	CEMA 7th Method *(User friction factor)*	DIN method *(Software results)*
FL	(-) 1312	(-) 1254	(-) 1277	(-) 1233
Empty	(+) 327	(+) 264	(+) 330	(+) 290
DL	(-) 1437	(-) 1394	(-) 1415	(-) 1374
IL	(+) 460	(+) 417	(+) 486	(+) 442

Table 6. Power demand/regeneration of conveyor 29.

9. DRIVE SYSTEM ASSEMBLY AND ARRANGEMENT

9.1 From the above calculations, considering the maximum power regeneration of about 1 437 kW from conveyor 29 and additional drive motor service rating of 10%, the installed drive power requirement is about 1 581 kW. In order to ensure uniformity and standardisation of drive components among the conveyors, three identical drive assemblies with 550 kW motors are proposed for conveyor 29 and two identical drive assemblies with 550 kW motors are proposed for conveyor 28 at their tail ends.

9.2 Braking torque requirements to stop the conveyors in 30 seconds are given below:

Loading condition	**Conveyor No. 28 (kN-m)**	**Conveyor No. 29 (kN-m)**
FL	186	369
IL	256	392

Table 7. Braking torque requirement.

9.3 Each drive assembly consists of a VFD controlled inverter duty LT induction motor (690V) of 550 kW at 1 000 rpm, a gear reducer of reduction ratio 1:20, disc brake of 220 kN-m braking torque capacity (selected based on motor torque) at the low speed side, low speed and high speed couplings.

9.4 The motor, brakes and gearbox components are intended to be mounted on a machined drive base platform. Drive base frames will be connected with pulley frames for better rigidity. The drive system will be installed at the tail end of the conveyors and the proposed arrangement is symbolically illustrated in Figure 5.

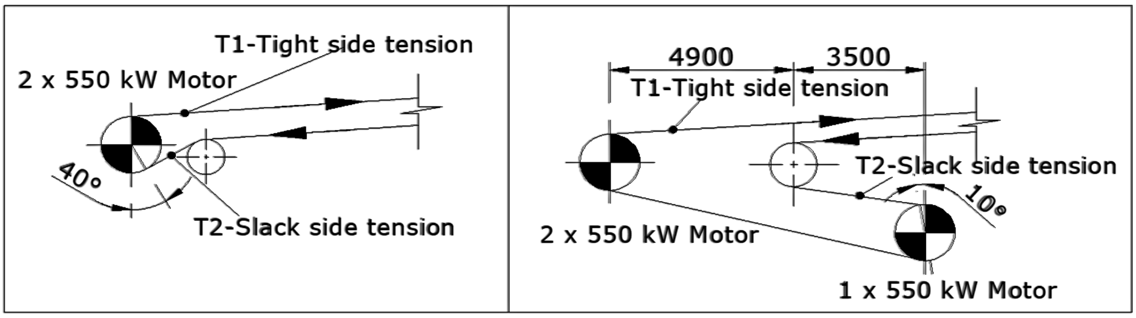


Figure 5. Drive arrangements proposed for downhill conveyors 28 and 29 at tail end.

10. STATIC ANALYSIS

10.1 Running tensions of conveyor 28 for various loading conditions were worked out (CEMA 7th Method with user defined friction factor) and the result of fully loaded belt condition is shown in the following graph.

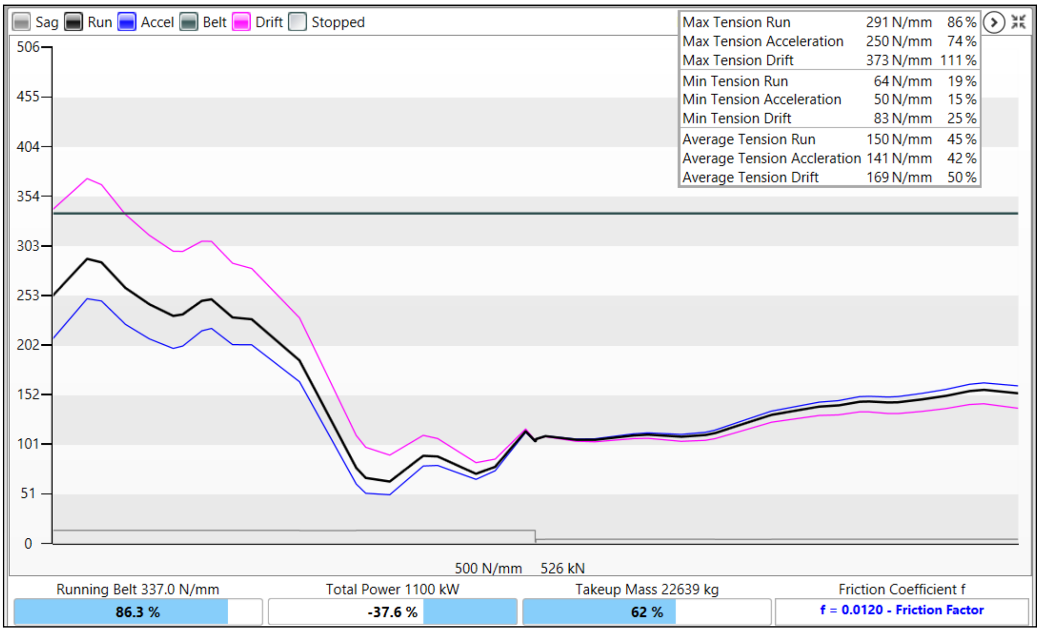


Figure 6. Running tensions of conveyor 28, FL (3 000 tph) condition.

10.2 Based on the tension results, the safety factor at which the existing belt ST 2 250 continues to operate is tabulated below.

Loading condition	Maximum running tension (N/mm)	Safety factor
FL (3000 TPH)	291	7.74
Empty	163	13.78
DL (3000 TPH)	363	6.19
IL (3000 TPH)	160	14.03

Table 8. Safety factor of conveyor 28 belt.

10.3 Running tensions of conveyor 29 for various loading conditions were worked out (CEMA 7th Method with user defined friction factor) and the result of fully loaded belt condition is shown in the following graph:

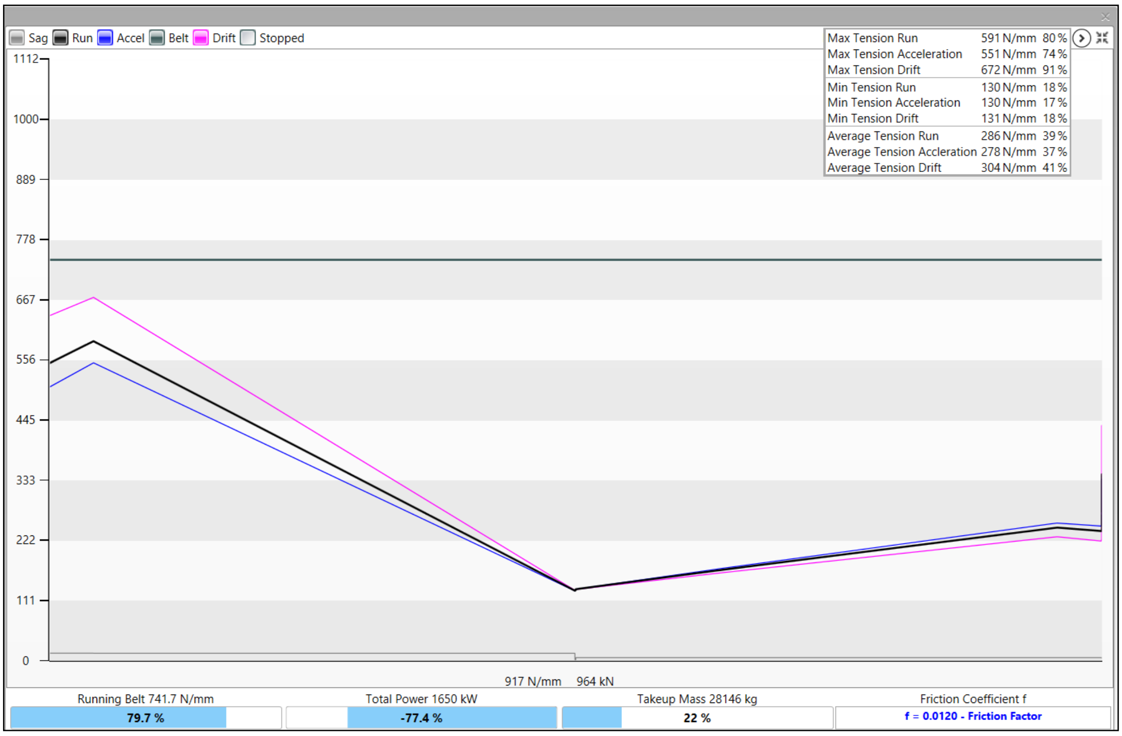


Figure 7. Running tensions of conveyor 29, FL (3 000 tph) condition.

10.4 Based on the tension results, the safety factor at which the existing belt ST 5 000 continues to operate is tabulated below.

Loading condition	Maximum running tension (N/mm)	Safety factor
FL (3000 TPH)	591	8.45
Empty	255	19.61
DL (3000 TPH)	592	8.45
IL (3000 TPH)	256	19.56

Table 9. Safety factor of conveyor 29 belt.

10.5 Note that the maximum running tensions of both the downhill conveyors after capacity upgrade are less than the existing maximum running tensions for which the conveyors are designed.

11. STARTING CONTROL – DYNAMIC ANALYSIS

11.1 The starting behaviour of the conveyors is studied for all the loading cases in various starting conditions.

11.2 The conveyors are to be powered by variable frequency drives (VFDs) of required capacity (suitable for regenerative conveyor application). VFDs provide good torque control and allow for an extended controlled start under any loading condition. The system will be configured with one of the drives acting as a master following a demand speed profile, while the other drives will act as torque followers.

11.3 When the start is called for, the drives are given a zero speed command. The brakes are then released over five seconds, transferring load from the brakes to the drives. The master drive then follows the speed ramp specified in Figure 8 for providing good starting control under all load conditions. The minimum acceleration time is proposed to be set at 60 seconds.

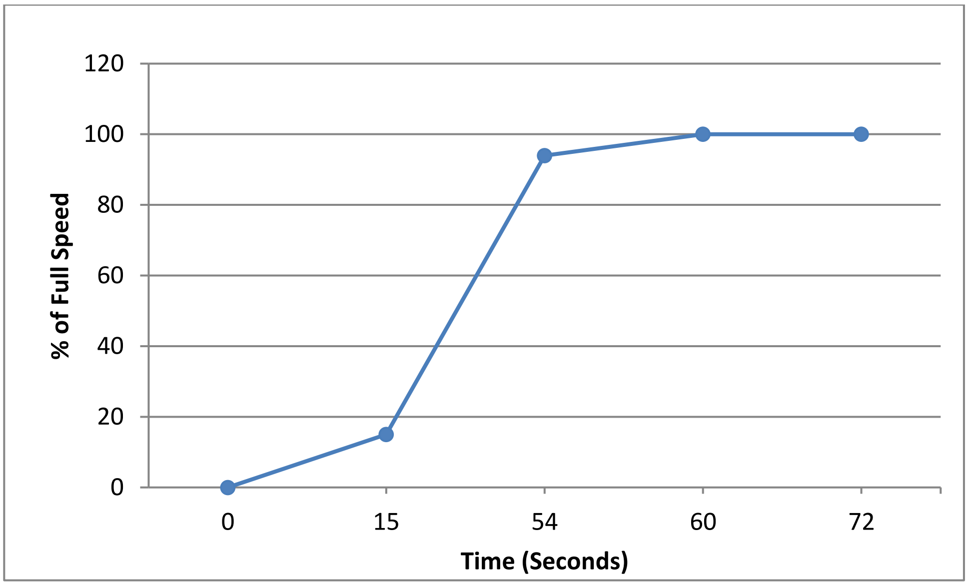
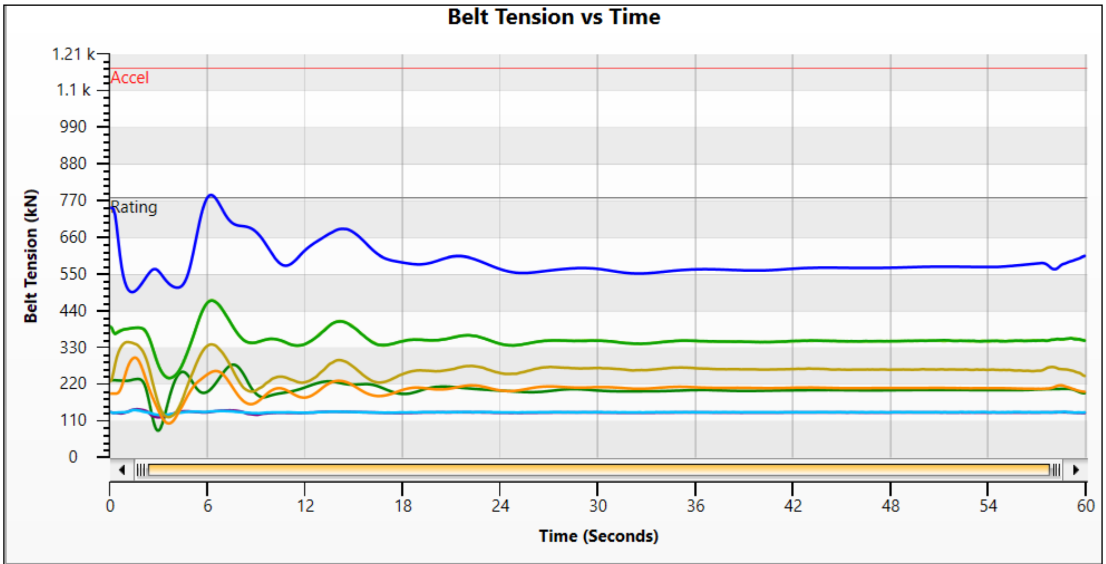


Figure 8. Starting curve.

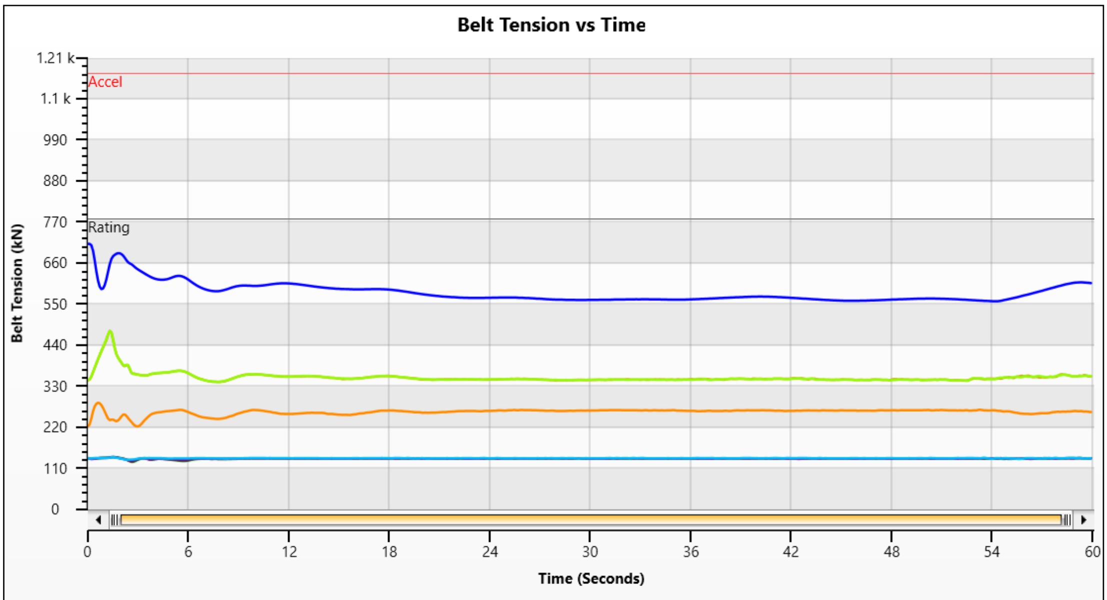
11.4 Figure 9 shows the starting tensions of conveyor 28 while starting in fully loaded (3 000 tph at 4 m/s) condition.



Description	Carry Max	Carry Min	Head	Takeup	Return Min	Drive #1	Return Max
Station (m)	202.36	2068.25	2410.13	2410.26	1218.33	1.28	1.17
Maximum	788.4	280.4	146.8	144.7	301.7	348.3	473.3
Minimum	498.1	82.7	122.7	129.9	104.1	123.1	240.7

Figure 9. Starting tensions of conveyor 28.

11.5 Figure 10 shows the starting tensions of conveyor 29 while starting in fully loaded (3 000 tph at 4 m/s) condition.



Description	Carry Max	Head	Return Min	Takeup	Drive #1	Return Max	Drive #2/Tail
Station (m)	202.36	2410.13	2410.20	2410.26	1.28	1.17	-0.04
Maximum	712.2	140.8	140.6	140.4	286.1	479.0	478.7
Minimum	558.4	127.8	129.7	133.6	223.1	342.2	342.1

Figure 10. Starting tensions of conveyor 29.

12. STOPPING CONTROL – DYNAMIC ANALYSIS

12.1 Considering the criticality and braking effort required to stop the conveyors, a secure, robust braking system is adopted.

12.2 During normal stopping, the VFDs simply ramp the system to 3% of speed within a pre-set time interval and thereafter, the mechanical braking system applies brakes for stopping the conveyors. This mode is used under normal conveyor operating conditions and thus load to mechanical brakes is minimised. This reduces the heat generation and mechanical wear of the mechanical brakes. The minimum stopping time is proposed to be set as 30 seconds and velocity ramp will be as shown in the Figure 11.

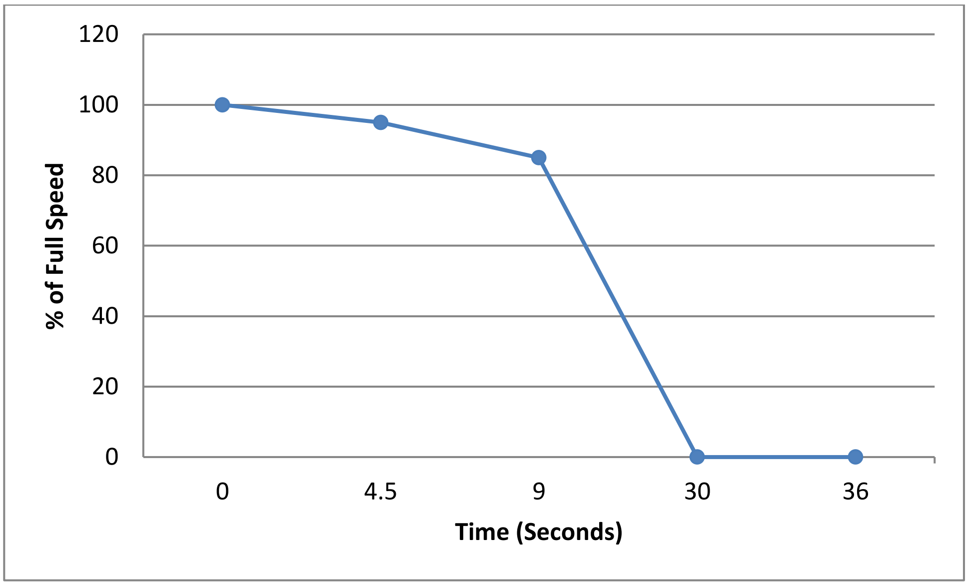


Figure 11. Velocity ramp during stopping.

12.3 During a power failure condition, VFDs will be powered by uninterrupted power supply (UPS) and the regenerative energy will be dumped to a large resistor bank (i.e., energy is dumped through chopper circuit to the suitably sized dynamic braking resistor made of FECRAL wire grid resistor and provided with natural air cooling). The conveyor will be ramped to stop in the pre-set time interval. Thus, VFDs ensure smooth stopping of the conveyor and reduce conveyor dynamic tensions to a greater extent. This ensures increased life of conveyor components including the belt.

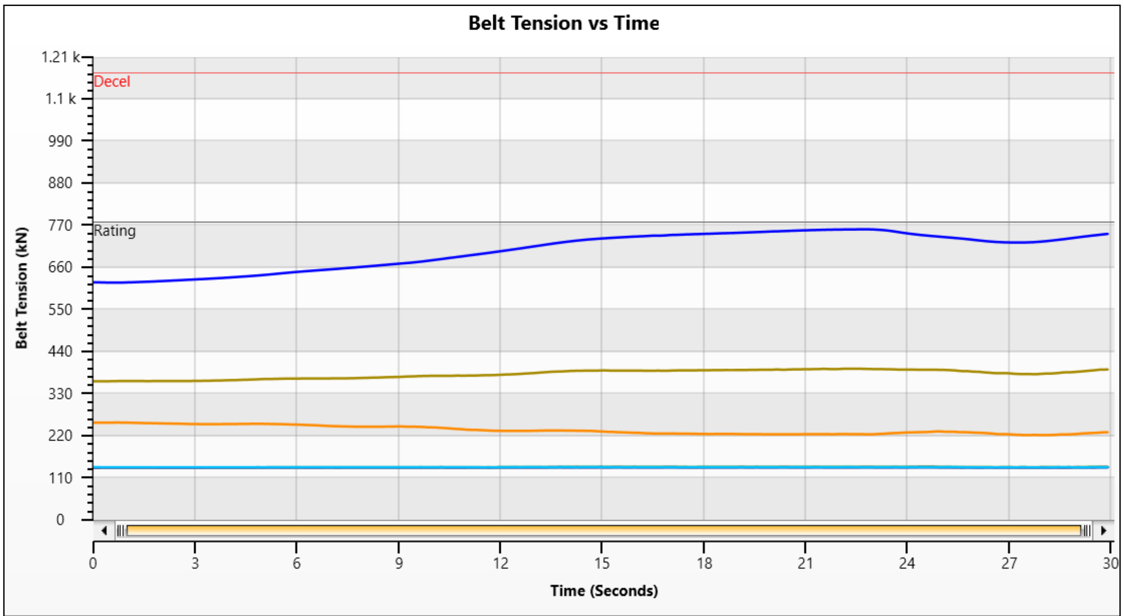
12.4 In the event of power and VFD controller failure, a brake controller modulates the brakes and brings the conveyor to rest in 30 seconds. In the unlikely event of brake controller failure as well, the brake dumps 50% torque immediately and bleeds to full torque over 10 seconds.

12.5 The conveyors have a robust, redundant braking system to stop the conveyor under all loading conditions. Spring applied hydraulically-released fail-safe disc brakes with a soft braking option are envisaged per drive at the low speed side.

The disc brakes are proposed to be mounted in the pulley shaft through hubs. One working and one stand-by hydraulic power pack for the brakes for each conveyor are envisaged. Two callipers per disc are provided. The brakes can control the conveyor in normal, power failure, VFD controller failure, brake controller failure and emergency mode of stopping, and during conveyor over speeding. Use of the soft braking option ensures application of braking torque over a pre-set period of time in a controlled manner.

12.6 PLC based brake controllers (one working and one stand-by) are envisaged for monitoring various features and the functions of the braking system, like monitoring of braking time, maximum speed, nominal speed, hydraulic pressure, brake pad temperature and other features like constant deceleration, controlled start-up ramp, controlled release of brake, key board locking and password function, alarm, event logging, control of electric motor hydraulic unit, battery back-up etc.

12.7 Figure 12 shows the stopping tensions of conveyor 28 when stopping the conveyor while fully loaded (3 000 tph at 4 m/s) normal condition.



Description	Carry Max	Head	Bend #2	Takeup	Drive #1	Drive #2/Tail
Station (m)	202.36	2410.13	2409.06	2410.26	1.28	-0.04
Maximum	760.0	138.7	137.9	138.2	254.7	395.5
Minimum	620.7	137.0	136.6	136.9	222.0	362.5

Figure 12. Stopping tensions of conveyor 28.

12.8 Figure 13 shows the stopping tensions of conveyor 29 when stopping the conveyor while fully loaded (3 000 TPH at 4 m/s) normal condition.

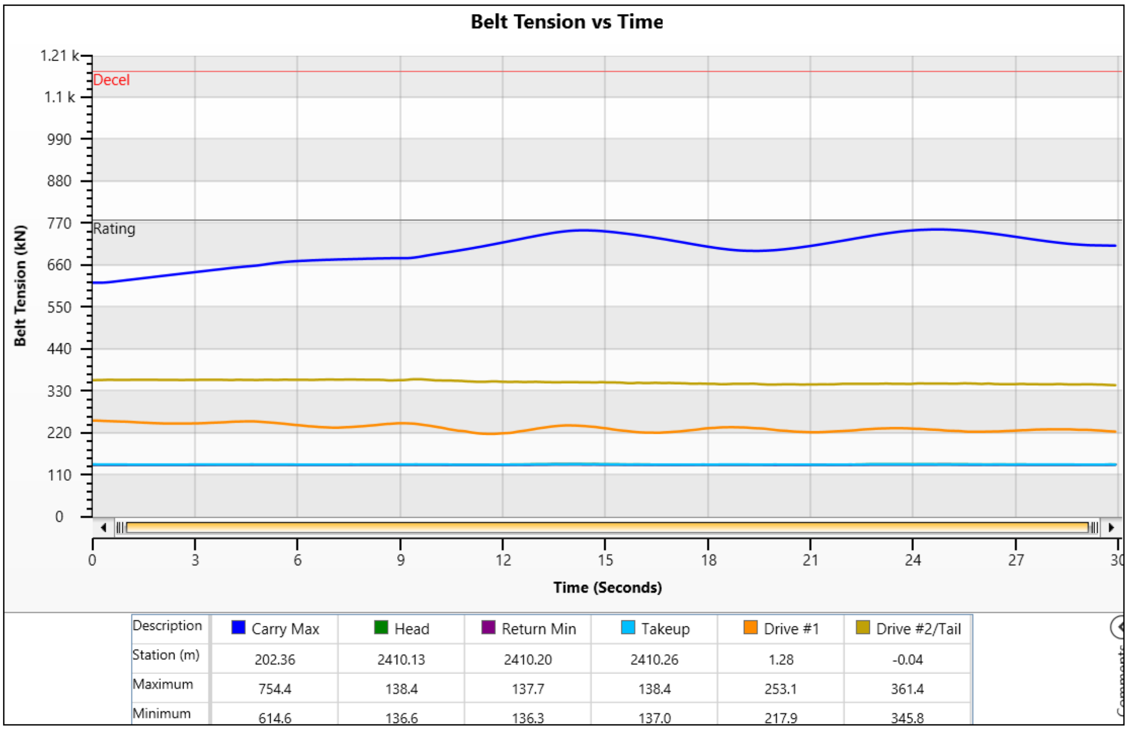


Figure 13. Stopping tensions of conveyor 29.

13. DRIVE HOUSES AND MOTOR CONTROL CENTRES

13.1 A well-equipped new drive house and motor control centre are planned for each conveyor at the tail end. These new drive houses will be constructed independently, away from the existing drive houses and without disturbing the day to day operation of the conveyors. On completion of construction, the new drive system will be connected by extending the tail ends of the respective conveyors.

13.2 Drive houses are suitably sized for accommodating the drive system and ensuring space for maintenance and men movement. Truck approach is provided and an EOT crane of capacity 15/5 tonnes is envisaged in both drive houses for handling requirements.

13.3 Drive house key plans for both conveyors, showing overall dimensions are given in Figure 14.

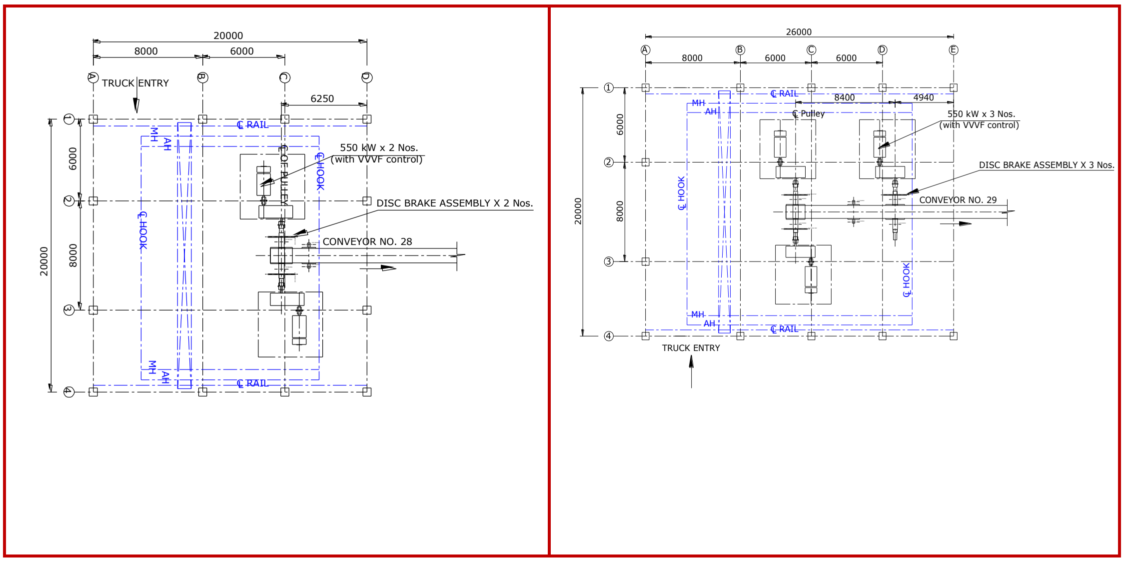


Figure 14. Key plans of proposed drive houses for downhill conveyors.

13.4 Location identified for the new conveyor drive houses and respective tail end extension requirements are shown in the following photographs:

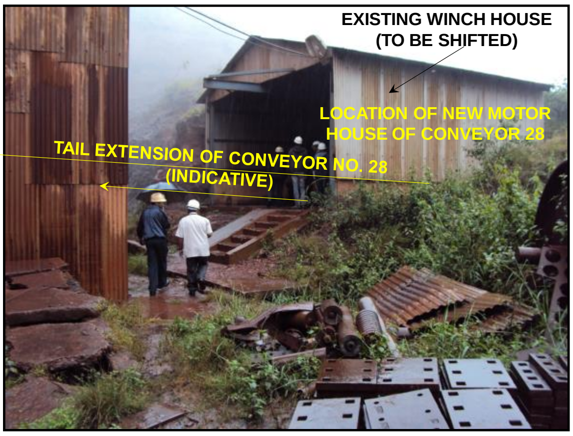
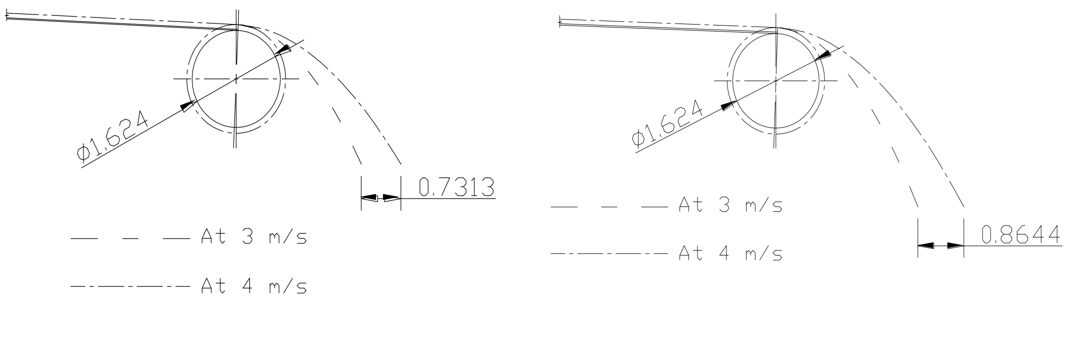


Figure 15. Tail end extension and new drive house location for conveyor 28.

Figure 16. Tail end extension and new drive house location for conveyor 29.

14. DISCHARGE TRAJECTORY

14.1 Trajectories of discharged materials for both conveyors were plotted in Figure 17 (dimensions shown are in metres) based on BIS 11592 and the increase in distance of fall at chute was considered to take up the necessary modification works in the discharge chutes.



Conveyor No. 28 Conveyor No. 29

Figure 17. Discharge trajectories of falling materials.

15. CONCLUSION

15.1 The paper summarises the important design considerations to be made in a brown-field capacity up-grade of a downhill conveyor system by striking a balance between the capacity augmentation requirement and existing constraints.

15.2 The front end engineering design helped in understanding the basic requirements of downhill conveyor systems. The static and dynamic analysis results of different operating and loading conditions helped in understanding the transient behaviour of downhill conveyors and thus arriving at the safe operating parameters and sizing of drive components.

15.3 The engineering carried out from the owner's side facilitated an estimate of upgrade requirements in advance and forms a baseline for meticulous execution and seamless integration through an EPC contractor.

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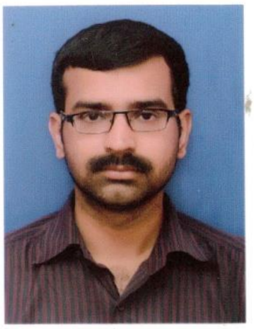

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