

MINIMIZING BELT WEAR AND DAMAGE FROM OPTIMIZED CHUTE DESIGN

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ABSTRACT

High tension steel cord belts are typically used in high tonnage, hard rock handling systems. Steel cords in conveyor belts can be damaged from impacting large rocks. Top cover may suffer excessive wear from accelerating the material to belt speed by friction. Wet, sticky material often plugs the chute, which also causes belt damage. Using Discrete Element Modeling (DEM) analysis, the transfer chute design can be optimized in order to minimize these problems and extend the service life of conveyor belts.

INTRODUCTION

Belt conveyor systems are often critical components to the productivity of a mine or process, and can cost tens of millions of dollars. Downtime loss due to conveyor component failure like belt damage can be even more expensive. It is important to maximize the belt's service life and reduce unexpected damage as much as possible. Besides splice fatigue life, the belt life is largely dependent on the top cover wear and steel cord damage which directly relates to the transfer chute design.

Traditionally, designers rely on their education, accepted design principles, past experience, and simple material trajectory calculation to develop transfer chute designs such as rock boxes to control the flow of the ore onto the receiving belt. More sophisticated approaches use scaled laboratory testing and proprietary designs tools.

Utilizing DEM, designers are able to study existing chute transfer problems, test new chute design concepts, and model different material conditions. These abilities have led to new innovations in chute design, including the curved chute or "spoon" geometry.

When a curved chute design has been fully tested and optimized for all of the conveyed materials using DEM software, substantial reductions can be seen in the abrasion and gouging damage to the receiving belt, as

well as minimizing the possibility of the chute plugging. These results increase the belt's service life, and reduce costly conveyor shutdowns.

In this article, the authors first discuss the chute design process utilizing DEM, and then illustrate three case studies.

DISCRETE ELEMENT MODELING

Overview

DEM simulates granular material systems consisting of discrete particles within which each individual particle is followed as it interacts with other particles and with the system boundary.¹ Over the last 30 years, with advances in computing power and numerical algorithms, DEM software has evolved immensely and is now able to simulate millions of complicated non-round particle shapes within acceptable time frames. Additionally, DEM software has expanded to integrate thermodynamics, computational fluid dynamics (CFD) and finite element method (FEM) programs. Today, the ability to model, analyze, and optimize the complex behavior of bulk materials flowing through transfer chutes has made the use of DEM software a powerful tool for the bulk materials transfer chute design process.

Conveyor Dynamics, Inc. (CDI) uses the Rocky DEM software from Granular Dynamics, LLC. An advanced DEM software package, such as Rocky, will include to the following features:

- Import a variety of 3D geometry formats.
- Ability to calibrate representative material sets containing complex non-round particle shapes.
- Analyze collected data to evaluate conditions such as liner and belt damage, power consumption, airflow, segregation, degradation, and much more.
- Integrate with CFD, FEA and other external software programs.

An advanced DEM software package coupled with an accurate material calibration and experienced design engineer will yield the best optimized chute design.

Material Calibration

Accurately calibrating a representative material within any DEM software is a critical component to achieving meaningful analysis results. Either on-site or in the laboratory setting, the actual materials being conveyed is tested with specially designed material testing devices. These devices enable CDI to measure the materials angle of repose and withdraw angles. Third-party material testing laboratories can also perform shear cell tests and measure material particle size and shape distributions.

Using the results of these tests, CDI is able to calculate material properties, such as adhesion and cohesion coefficients, and static and dynamic friction values for both the material and boundary, that can be entered directly into the Rocky DEM software.

Once the calculated parameters have been entered into Rocky, the angle of repose and withdraw test is simulated to ensure the material is calibrated properly.

Results Analysis

Qualitative and quantitative results are generated from DEM chute simulations. Qualitative results include the flow of material, and the location of material on the receiving belt. The flow of material allows the designer to adjust chute geometry so that the trajectory of the material follows the intended path. Centering of the material on the receiving belt reduces belt mis-tracking.

Belt wear and damage are analyzed in two quantitative results—that is, abrasion (shear) and gouging (tearing). Abrasion is measured by multiplying the applied pressure by the amount of slippage (MPa-m) between the rock and belt or liner it is in contact with, counting from the point of loading to the end of the sliding region.²

Gouging is defined as a tearing action. If a rock is sharp enough and has sufficient pressure between the rock tip and belt surface to exceed the yield strength of the material it is impacting, then the impacted material will crack or tear. The degree of damage depends on the force and sharpness of the rock, and on the shearing action between the rock and belt or liner due to their relative speed differences. Given that the rock sharpness and contact attitude is probabilistic within the ore stream, the only measurable value of certainty is the rock pressure (mPa) and amount of rock slippage on the belt. Therefore, we establish the likelihood or degree of gouging damage from mapping the pressure and slippage field at the loading station across the belt's width.²

The quantitative results can be visualized in colored contour maps on belt and chute surfaces, such as shear wear on the receiving belt shown in Figure 1, and the gouging damage on chute liners shown in Figure 2. This ability enables designers to quickly see where the high

wear zones are, and make modifications to the chute designs accordingly.

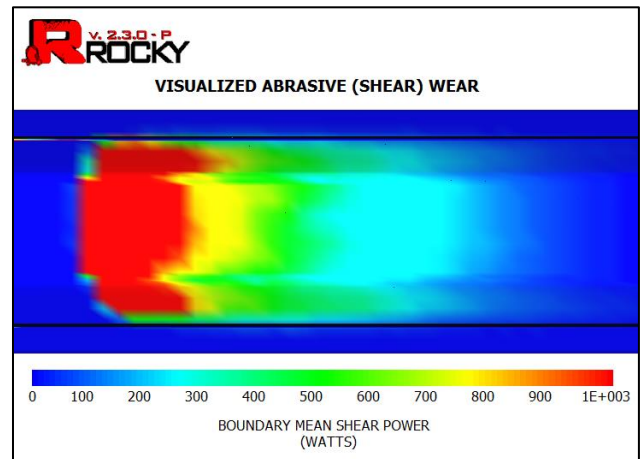


Figure 1. Visualized Abrasive (Shear) Wear

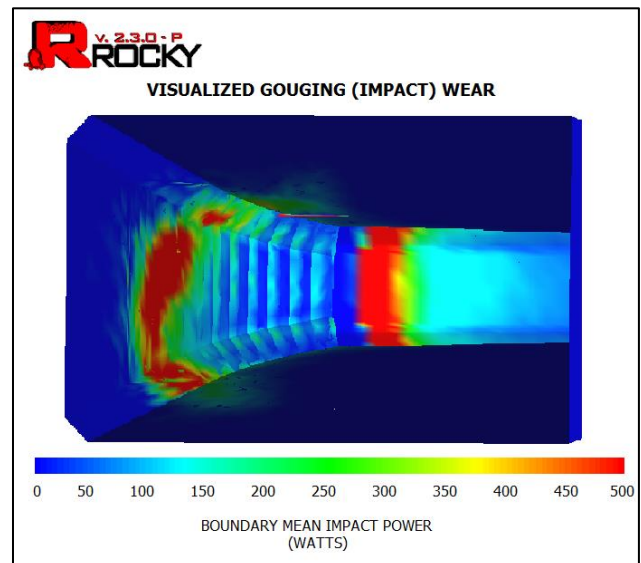


Figure 2. Visualized Gouging (Impact) Wear

Figure 3 shows the contact pressure across the width of the receiving belt, and can be used to determine if the pressure being applied by the material is below the yield strength of the rubber. In this example, the pressure

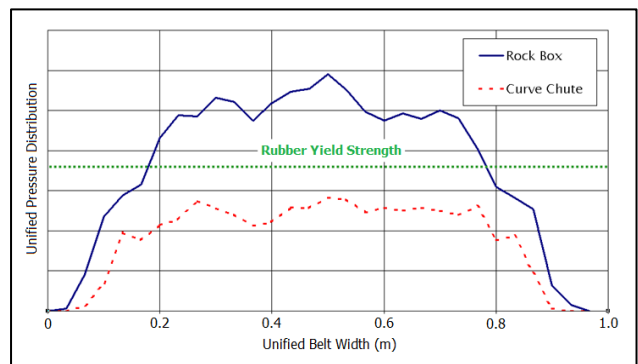


Figure 3. Pressure Integrated Over a Specific Belt Length

applied with the curved chute design is below the rubber's yield strength, which indicates no gouging will occur. The ability to easily analyze the chute liner and receiving belt wear, as well as how well the material is centering on the receiving belt, are indispensable tools when optimizing curved chute designs.

Curved Chute Design

An optimized curved chute design controls the flow of material, placing it onto the receiving belt where the material's forward velocity approximates the belt's speed, minimizing abrasive degradation, and where the material's design impact pressure is below the belt cover's critical gouging damage threshold.³

An optimized curved chute design reduces:

- The need for thicker belt top cover
- Impact damage on steel cords by large rocks
- Rip and puncture damage from metals
- Spillage and its related damage at the transfer station

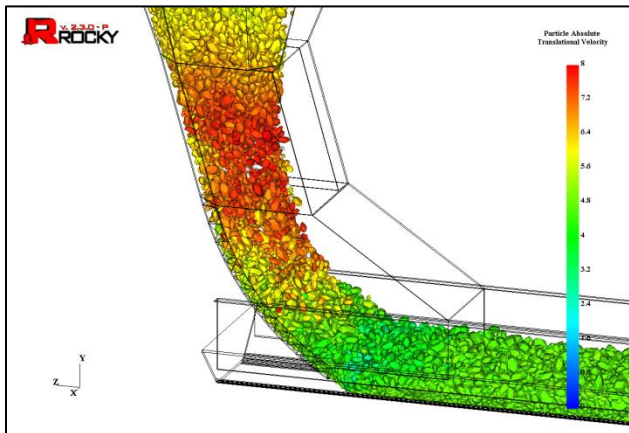


Figure 4. Optimized Curved Chute Design

Multiple Material Conditions

One of the most common and difficult chute problems is plugging by wet, sticky material. Such chutes often also transfer dry materials that have different flow characteristics to the wet materials. As a result, the chute design has to accommodate multiple material conditions.

Trade off conditions must be evaluated in selecting the proper curvature and exit angles. With a given drop height, dry materials will have greater exit velocities over wet materials. As a result, the optimal curve radius and exit angle must be found that results in the least amount of damage to the chute liners and receiving belt from dry material while still enabling wet material to flow and not plug the chute. This can sometimes be difficult to accomplish, can take a lot of design iterations, and relies heavily on the designer's experience and engineering judgment.

CASE STUDY 1: PALABORA

The Parabola Mining Company (Palabora), located adjacent to the Kruger National Park in South Africa, mines copper in an open-pit operation. One of the main incline tunnel conveyors in Palabora transports 6500 t/h copper ore using a 1800 mm wide ST6600 belt. A conventional rock box was designed to control the ore flow onto the incline conveyor from the belt feeder under the primary crusher. After only 3.5 years of operation, the top cover of the ST6600 belt wore down until the tensile cords began to show through the 18 mm thick top cover. The original belt warranty was for 10 years. The worn belt profile is shown in Figure 5. The belt profile showed the wear zone matched the width of material cross section closely, which indicated the wear was due to the transfer rock box design.

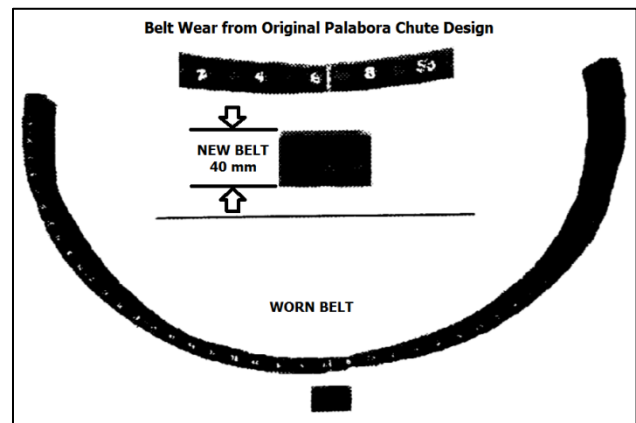


Figure 5. Worn ST6600 Belt Profile from the Original Palabora Chute

Palabora sponsored a study to determine the wear mechanisms and improve the installed rock box design with their 5,000 t/h nominal and 6,500 t/h peak flow rates.^{2,3}

The original Palabora chute consisted of a hood over the head pulley, and a rock box to control the discharge onto the receiving belt. Rock box chute geometries are widely used in the conveyor industry due to their simplicity, and minimized wear and required maintenance on the chute's interior surfaces. Unfortunately, rock box designs do not necessarily protect the receiving belt from abrasion and gouging damage.

With a conventional rock box design, like the one installed at Palabora, material builds up on the horizontal ledges until it reaches its natural angle of repose, at which point the material slides off the static pile directly onto the receiving belt. In most cases, this condition causes the material's forward velocity in the direction of the receiving belt to be slowed or stopped all together. If the rock box also contains a "V" shape discharge opening, like Palabora's did, the ledge around this opening causes part of the material flow stream to be routed along the

sides and then discharged onto the main flow stream at nearly 90 degrees, further decreasing the materials forward velocity.

CDI determined that the high abrasion wear was created by the material sliding on the belt during acceleration, which caused excessive belt top cover wear. Additionally, some gouging damage may have been occurring to the belt from sharp rocks impacting the belt.

The new design, proposed by CDI, replaced the rock box with a curved chute design. The angled back wall of the curved chute reduces the material's free fall distance by interdicting the material flow closer to the head pulley. In addition to helping control and center the material, this feature results in a lower impact angle and velocity at the initial chute contact point, and higher overall velocities through the chute. Therefore, the main damage to the liner material is abrasion, not impact. As a result of the curved chute geometry, the material's impact angle to the receiving belt is decreased, which will reduce the gouging or impact wear. Additionally, the discharge velocity is near the receiving belt speed of 4 m/s—twice that of the rock box—which will result in a reduction in abrasive belt wear.

Six months after the curved chute design was installed and became operational, CDI inspected the belt and found no evidence of pitting or gouging. The belt surface was smooth, and when a straight edge was placed across the belt width, there was no indication of any local wear depressions. Two small 150 mm slightly roughened regions were found and are attributed to ore turbulence caused by small rail bars, both on the side walls, placed in the line of flow, near the chute exit, by the maintenance staff. CDI believed these were supposed to act like ore stream centering devices, usually found in rock boxes. They were targeted for removal. The two small roughened zones appeared to have less than 2 mm of wear. Elsewhere, no more than 1 mm of wear was noted.³

Palabora diligently monitored the belt's wear progress every six months for 3.5 years, and at the end of that time, only about 2 mm of overall wear had been measured. This extrapolates to a 30 year belt life expectancy from the 18mm belt top cover.²

CASE STUDY 2: LOS PELAMBRES

Los Pelambres, located 200 km north of Santiago and 45 km east of Salamanca in the Choapa Province, mines copper in an open-pit operation. Los Pelambres has one of world's biggest downhill conveyor systems, in terms of tonnage, regenerative motor power and belt rating. One item in CDI's scope of work was to design and later upgrade the CV-005 to CV006 transfer chute, identify areas of concern, and then develop new chute geometries to accommodate the new design flow rate of 9,900 t/h at 6.8 m/s, and a future flow rate of 11,000 t/h at 7.6 m/s.

A DEM simulation of the original chute sent to CDI for review was created with the existing throughput of 8,700 t/h at 6.0 m/s (Figure 6).

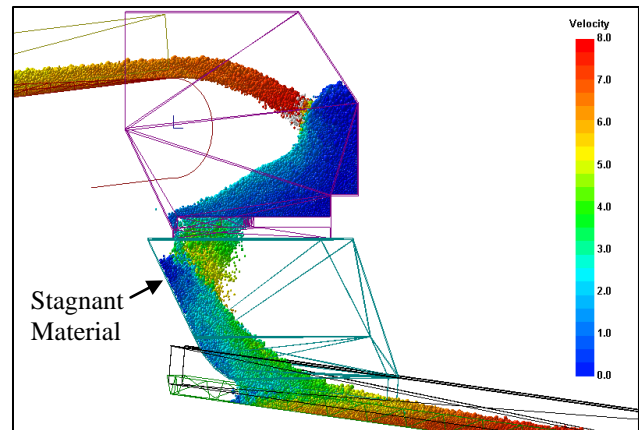


Figure 6. Original Design; 8,700 t/h at 6.0 m/s

After the DEM analysis was completed, the following primary areas of concern were identified:

- There does not appear to be enough material built up in the hood to provide adequate protection for the chute walls.
- Once the material leaves the hood, it falls onto the back wall of the lower curved chute geometry and begins to stagnate as designated by the dark blue areas in Figure 6.

To address the areas of concern, CDI proposed a transfer chute design consisting of modified hood and curved discharge chute geometries.

The modified hood (Figure 7) was widened by 1 m to accommodate new side wall baffles, which force material to build up within the hood and creates a larger layer of protection for the chute walls. The discharge opening was also modified to better direct the material flow into the modified curved discharge chute geometry.

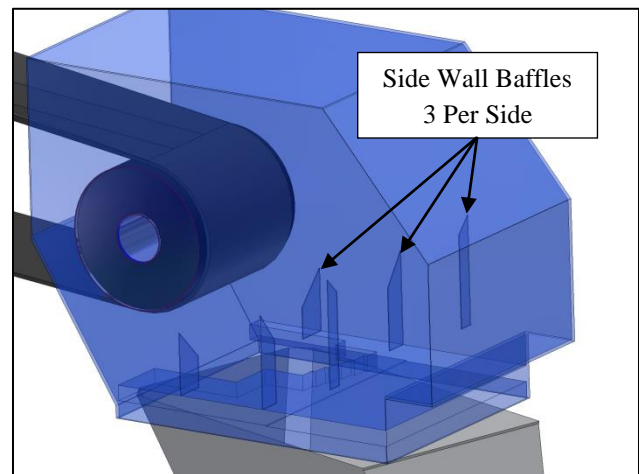


Figure 7. Modified Hood Geometry with Baffles

The curved discharge chute geometry was modified to be symmetrical with the centerline of the receiving belt,

and the back wall angle was increased from 70 degrees to 75 degrees. Chamfered corners were added to any surfaces that material comes into contact with to help to center the load as the material rides on the surface. Lastly, the bottom of the curved chute geometry was lowered to have a 150 mm clearance to the belt, and the discharge angle at the end of the curved chute geometry was set to 20 degrees to horizontal.

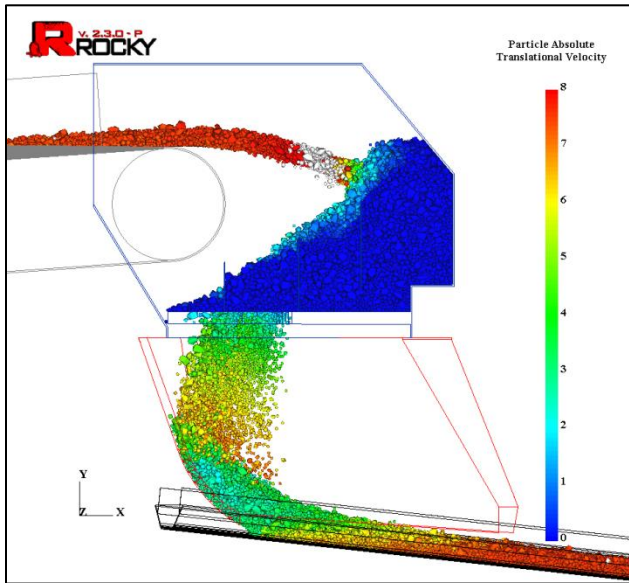


Figure 8. Proposed Chute; 11,000 t/h at 7.6 m/s

Analysis of the DEM simulations showed that, for the new design flow rate of 9,900 t/h at 6.8 m/s, both the abrasion and gouging wear are reduced by approximately 36 percent. For the future flow rate of 11,000 t/h at 7.6 m/s, the analysis showed reductions in abrasion and gouging wear of 10 and 6 percent respectively.

In year 2000, the first full production year of the Los Pelambres mine, over 34 million tons of ore passed through the chute, and the tonnage has increased to 65 million tons per year through several upgrades. The transfer chute fulfilled the design intent to minimize belt top cover wear, chute wear, and prevent plugging.

The Los Pelambres project demonstrates how designers can use DEM to help identify areas of concern, and then modify their designs to address them.

CASE STUDY 3: ASH GROVE CEMENT

Ash Grove Cement Company (Ash Grove) is headquartered in Overland Park, Kansas, USA, and operates eight cement plants in eight states with an annual production capacity of nearly nine million tons of cement.

The Ash Grove cement plant located in Seattle, WA contracted Transco Northwest, Inc. (Transco) to evaluate and redesign the chute in their existing tower six transfer point (TT6) with a 1 year performance guarantee the chute will not plug while conveying any one of following materials.

- Sumas Shale
- Boiler Ash
- Limestone
- Cominco Slag
- Iron Grit
- Port Hardy Silica
- Bottom Ash



Figure 9. Ash Grove Cement Company, Seattle Plant, Original Design at TT6

Transco requested the assistance of CDI to perform DEM analysis of the chute, identify areas of concern, and suggest design improvements.

The original chute configuration consisted of a single discharge conveyor, an asymmetrical gate, and two legs, one of which has a rock box at its discharge. The design throughput was 200 tph and the conveyor information used to configure the DEM simulations is shown in Table 1.

Table 1. Conveyor Information

Conveyor	Belt Width (in)	Belt Speed (m/s)	Incline Angle (deg)	Alignment Angle (deg)
CV152.100	26	1.56	13.34	0
CV155.020	30	1.58	14.11	76.5
CV155.030	24	1.82	14.11	76.5

Ash Grove expressed that their primary concern was wet material regularly plugging the chute in the lower 45 degree lateral leg coming out of the gate. Based upon this information, CDI calibrated a "worse case" representative material within the Rocky DEM software that plugged the chute as described by the client (see Figure 10). A separate representative material set was also created for simulating dry material conditions.

After performing DEM analysis on both legs of the original design, the following areas of concern were identified:

- The slope of the CV155.030 chute leg is not steep enough to prevent wet/sticky material from stalling and plugging the chute.
- The rock box at the bottom of the CV155.030 chute leg causes the material to lose too much

velocity prior to being discharged, which could also cause plugging in this area.

- There is significant material buildup on the deflector plate in the hood, both sides of the gate, at the elbows of both chute legs, and along the bottom corners of the both chute legs.

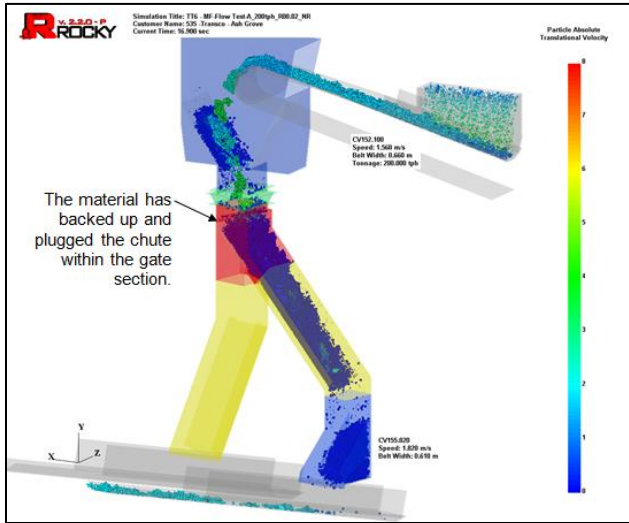


Figure 10. TT6 - CV155.020 Leg [Original Design], Wet Material

To address the areas of concern, the new design proposed by CDI consists of a shifted head pulley with new skirting, an upper adjustable deflector plate, as well as a completely redesigned hood, gate section, and chute legs.

In order to increase the slope of the lower chute legs, the head pulley is shifted back by 8 feet and the transfer chute is redesigned to be symmetrical. Skirting is added above the head pulley to consolidate the material, reducing the amount of spray coming off the sides of the deflector plate as well as the amount of buildup within the hood and its transition to the gate section.



Figure 11. Deflector Plate

The redesigned hood encompasses the 76.5 degree transition to accommodate an adjustable deflector plate.

The deflector plate (Figure 11) located within the hood is tapered and contains curved bends in lieu of chamfered corners, which direct the material through the bottom opening of the hood and onto the center of the diverter gate. The deflector plate's position can be adjusted both out-of-plane from the head pulley, as well as angularly, to allow it to be tuned in the field for optimal material flow.

The gate section is redesigned to be symmetrical and centered between the two receiving conveyors. The gate contains tapered chamfers on both sides to keep the

material centered as it exits the gate section and travels into the chute legs. The chute legs are symmetrical with respect to the gate section. The slope of the upper leg sections is 65 degrees, while the lower leg sections have a 70 degree slope. These angles result in higher material velocities through the leg sections, which when coupled with the low impact angle at the 90 degree turn in the legs, and chamfered corners to center the material within the chute, help reduce the amount of material buildup (see Figure 12).

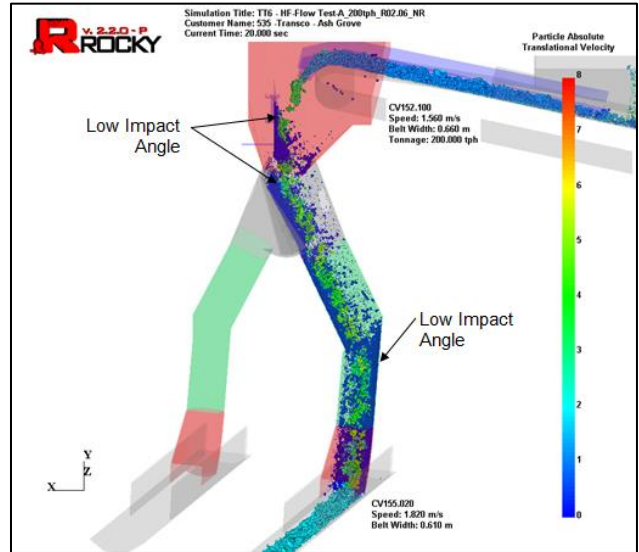


Figure 12. TT6 - CV155.020 Leg [Proposed Design], Wet Material

Lastly, the curved spoons are designed to slow the material before discharging onto the receiving conveyors and the chamfered corners, which match the legs, continue to center the material (see Figure 13).



Figure 13. Lower Discharge Chute Geometries; Original Above; New Below



Figure 14. Ash Grove Cement Company, Seattle Plant, Proposed Design installed at TT6

While there are areas of build-up where the material impacts a surface or along the bottom corners of the chute, the amount of build-up is less than the original chute. This is also due to the reduced impact angles and constant velocity of the material, as well as the slopes or angles of the chute being steeper.

All of these changes enable wet material to flow through either side of the chute without any concern of plugging.

After 1.5 plus years of being in operation, Ash Grove reports the chute has had no issues with plugging, and fully has met their performance requirements.

SUMMARY

This paper discussed how to minimize belt wear and damage by utilizing discrete element modeling (DEM) to optimize chute design. The importance of using an advanced DEM software package, and an accurate material calibration, as part of the design process are outlined. Three case studies were reviewed demonstrating the benefits of using curved chute geometries to control the flow of both wet and dry materials, and ultimately extend the service life of the receiving belts.

ACKNOWLEDGMENTS

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