Optimizing an Engineered Slope Conveyor System – An OEM / Operator Collaboration

Todd Burchett, Product Manager, Caterpillar
Brian Young, Project Engineer, Caterpillar

Introduction

Mining engineers spend countless hours and resources when designing a new underground coal mine. Their primary objective is to design the safest and most efficient operating mine with regards to coal production. A key variable often overlooked in this design stage is the slope conveyor. Typically, a slope conveyor is expected to operate with a 98% or higher availability, however, little effort is put forth by the mining engineer to optimize its design. Coal companies will rely on Engineering, Procurement, Construction, and Management (EPCM) companies for the preliminary design because the slope conveyor will be considered part of the surface material handling processes. This preliminary design will be used when soliciting quotations for the slope conveyor. Unfortunately EPCMs may not have enough expertise with conveyors to optimize the design. This expertise is available with an original equipment manufacture (OEM) of conveyors, which ultimately may be responsible for supplying the slope conveyor. Each OEM will provide a bid package that represents what they consider to be the optimal design. While this may be good to get a sense of design possibilities for the slope conveyor, it makes comparing quotes very difficult for the operator. Instead the operator will take portions of each bid package, create a revised design, and request a new quote. This process is then repeated several times and in fact the bid process itself becomes the design optimization. Not only is this a time consuming exercise, but it is also very inefficient. However, if an OEM is involved in the initial design of the slope conveyor and collaborate with the operator to determine a uniform set of specifications, then the operator could solicit a request for quote that would allow them to easily compare bids for an optimally designed conveyor.

Caterpillar Global Mining LLC (Caterpillar) was contacted by a coal mining operation in Mexico (operator) to review the preliminary design of a slope conveyor for a new longwall mine. The operator had contracted an EPCM to provide this preliminary design and write the technical specifications for the request for quotation. The EPCM did provide a conceptual drawing, as well as some general specifications for this design. Caterpillar was asked to review this design to determine its viability and to present any recommendations to optimize the design. A meeting at the mine site between the operator and Caterpillar was held to discuss these findings, collaborate on any recommendations, and finally determine the optimum design for this slope conveyor. This paper presents how the approach of an OEM / operator collaboration has proven successful.

Preliminary Design Review

In 2011, Caterpillar was asked to review a preliminary slope design for a new longwall mine in Mexico. Table 1 shows the preliminary design specification data. Presumably the EPCM provided three different and viable design scenarios that the operator wanted to explore. All three included variations in the radius of the curve at the bottom of the slope (which will affect the overall length of the conveyor), the belt width of the conveyor, and the speed of the conveyor. A drawing was also provided to show the slope design layout (Figure 1). The operator requested that Caterpillar evaluate the three design options. Option 1 was to be a 60" slope conveyor running at 4.5 m/s. Option 2 was to be a 72" slope conveyor running at 4.5 m/s. Option 3 was to be a 72" slope conveyor running at 3.5 m/s. All three options were to be evaluated at 5,500 mtph.

Table 1: Preliminary Design Specifications

	Option 1	**Option 2**	**Option 3**
Material Density	**881 kg/m^3**	**881 kg/m^3**	**881 kg/m^3**
Belt Width	**60"**	**72"**	**72"**
Length	**1,086 m**	**1,111 m**	**1,357 m**
Lift	**233 m**	**233 m**	**233 m**
Belt Speed	**4.5 mps**	**4.5 mps**	**3.5 mps**
Horizontal Curve Radius	**2,956 m**	**1,251 m**	**2,865 m**
Desired Tonnage	**5,500 mtph**	**5,500 mtph**	**5,500 mtph**

Drawing Review

The preliminary design layout drawing provided (Figure 1) shows a slope conveyor that transports the run of mine (ROM) coal from underground and discharges the material directly onto the ground above a reclaim tunnel. The design includes a radius of curvature at the bottom of the slope to properly transition the conveyor from horizontal to an incline of 15.75°. This angle is maintained until reaching the surface. Immediately outby the portal is a four-pulley drive assembly, which includes two bend pulleys to properly transfer the belt into and out of the drive. Outby the drive assembly the incline is decreased to 7.78° which is maintained until reaching the discharge (or head) that is elevated 20.5 m above the ground. This portion of the conveyor will be supported by a truss structure. Also, on the return side of the slope conveyor, approximately halfway between the four-pulley drive assembly and discharge, there is a gravity take up assembly.

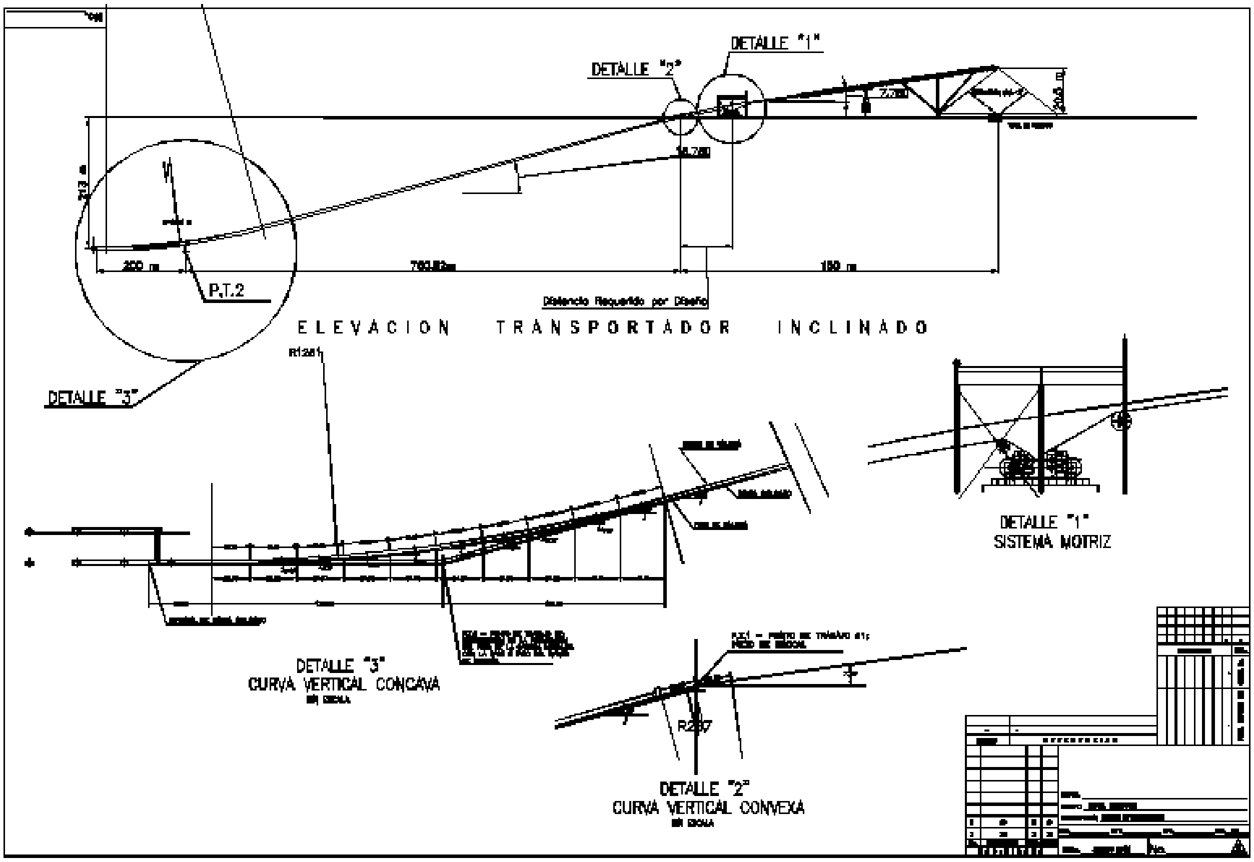

Figure 1. Preliminary Slope Design Layout Drawing

The first issue with this layout was the location of the gravity take up. As seen in Figure 2, the take up is located outby the drive assembly. In this location the required take up tension is close to the maximum tension seen throughout this slope conveyor. The highest tension is seen at the discharge (head) of the conveyor and locating the take up between the discharge and drive assembly is inadvisable and could be unsafe for the operator. For example, if the take up were placed in this location for Option 1 the counterweight would need to weigh almost 200 tons; obviously this is not practical. The only practical location for a gravity take up on the surface is inby the drive. This location allows for a more manageable counterweight; however there are some advantages and disadvantages to a gravity take up that will be discussed later.

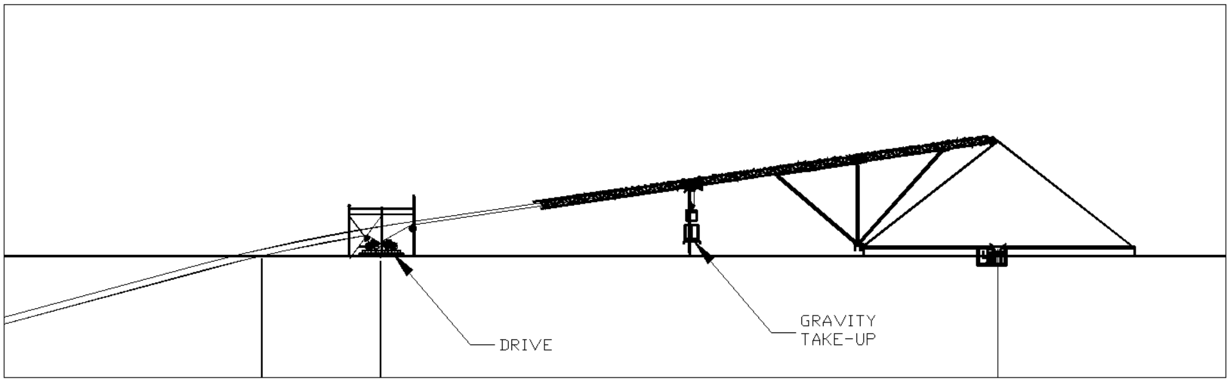

Figure 2. Initial Location for Gravity Take Up

The next issue is a design weakness from an economic standpoint more than an operating concern. The preliminary design layout shown in Figure 3 is a four pulley drive assembly located on the surface underneath a truss frame structure. To properly transfer the belt in and out of the drive requires two bend pulleys, one inby and one outby the drive assembly. The bend pulleys are shown attached to the truss structure, which proved to be the primary reason for this structure. Also, the bend pulley located directly outby the drive will need to be a high-tension pulley.

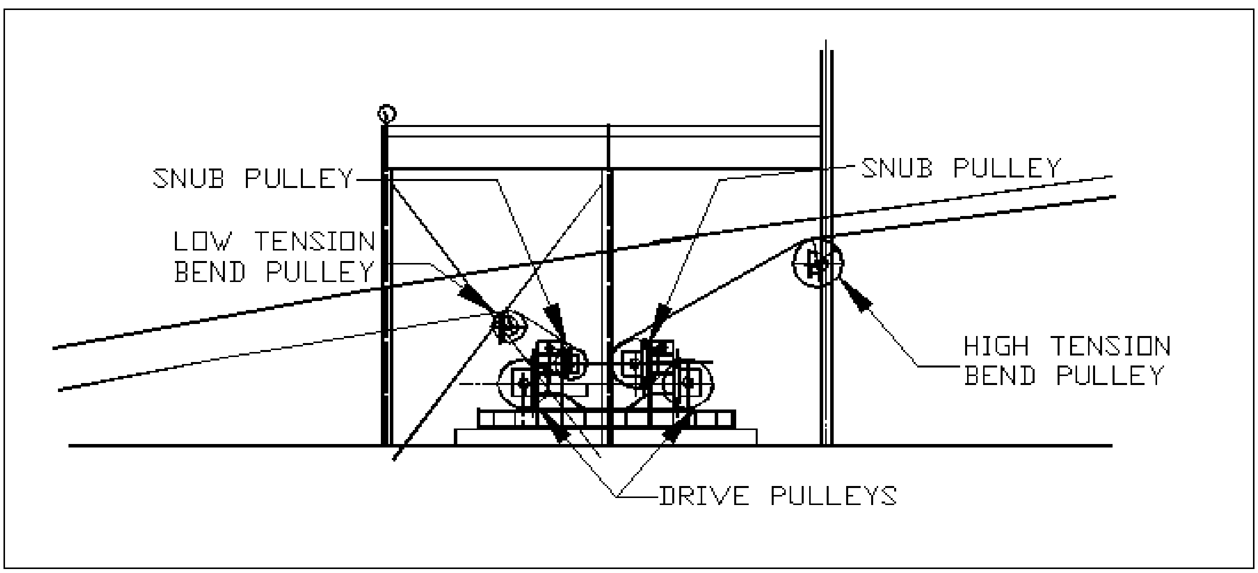

Figure 3. Preliminary Design Drive Arrangement

From a design standpoint this drive layout appears to be appropriate, and in fact many slope conveyors use this very design. The primary reason for a four pulley drive arrangement is that it allows less belt slippage due to driving only on the clean side of the belt. However, if the belt is properly maintained with belt cleaners, this design becomes redundant, and unfortunately adds undue capital cost for the operator. The alternative to this design is a two pulley drive assembly layout. Moving the drive assembly closer to the portal of the slope eliminates the need for the high tension bend pulley. This two pulley design will be discussed in further detail later.

Technical Specification Review – Option 1

Since Option 1 is a 60" belt width design, it first had to be determined if this is a viable option at 5,500 mtph. Using Belt Analyst™ software by Overland Conveyor Company Inc., Caterpillar determined that the maximum capacity for this option is 3,750 mtph (4,134 stph) at 4.5 mps (886 fpm) (Figure 4). Therefore this option was eliminated based on capacity constraints.

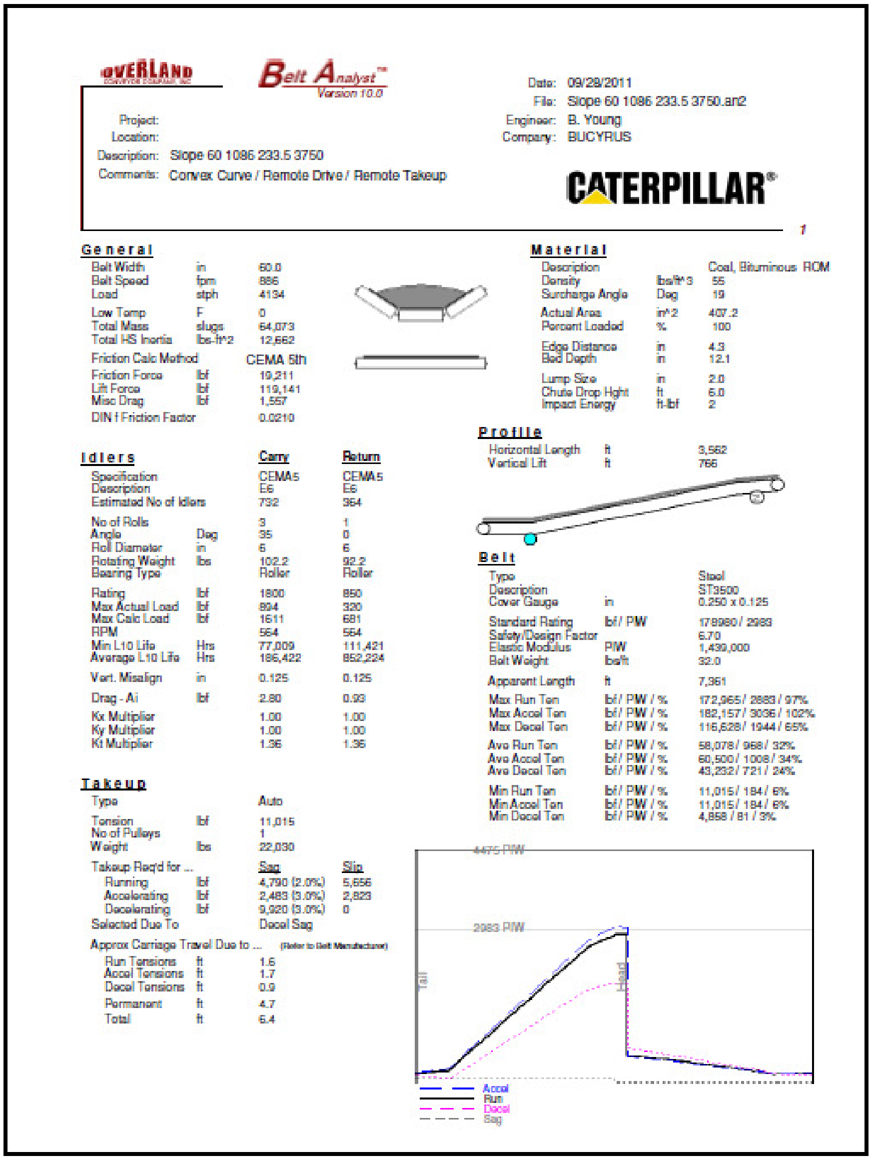

Figure 4. Belt Analyst Output for Option 1

Technical Specification Review – Option 2

The design specification for Option 2 is a 72" belt width with a capacity of 5,500 mtph (6,063 stph) at 4.5 mps (917 fpm). From Figure 5, the Belt Analyst™ summary shows that this option is capable of running 5,500mtph based on a 97% volumetric load capacity. Option 2 requires a total of 6,400 hp and a take up that can apply 15,453 lbf belt tension (or 30,906 lbf counterweight), when placed at the bottom of the slope near the tail. The belting requirement is a steel cable ST4000 belting that has a rating of 3,411 PIW. The overall horizontal length of this conveyor is 1,111m (3,644 ft) which includes a vertical curve with a 1,251 m (4,104 ft) radius at the bottom of the slope.

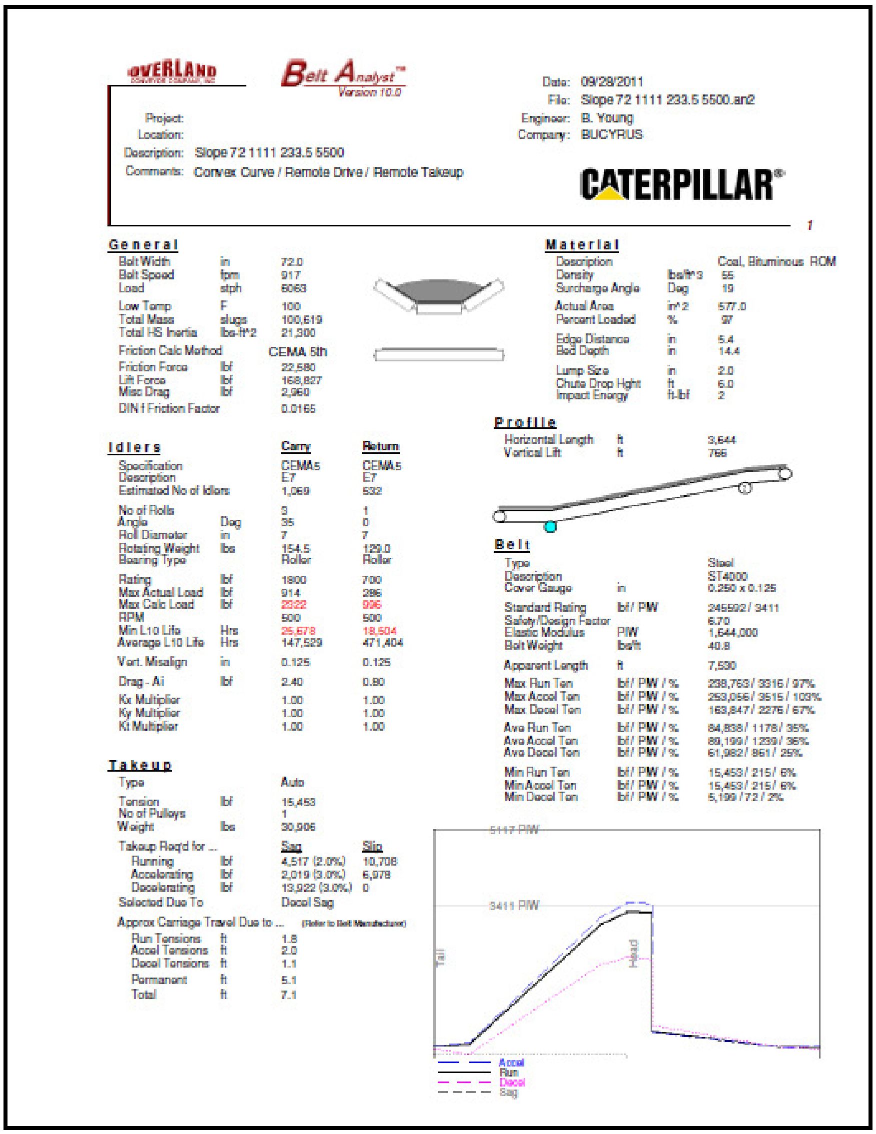

Figure 5. Belt Analyst Output for Option 2

Technical Specification Review – Option 3

The design specification for Option 3 is a 72" belt width with a capacity of 5,500 mtph (6,063 stph) and a speed of 3.5 mps (689 fpm). From Figure 6, the Belt Analyst™ summary shows that at a belt speed of 3.5 mps, the maximum capacity is 4,250 mtph (4,685 stph). Therefore, this was deemed not to be a viable option.

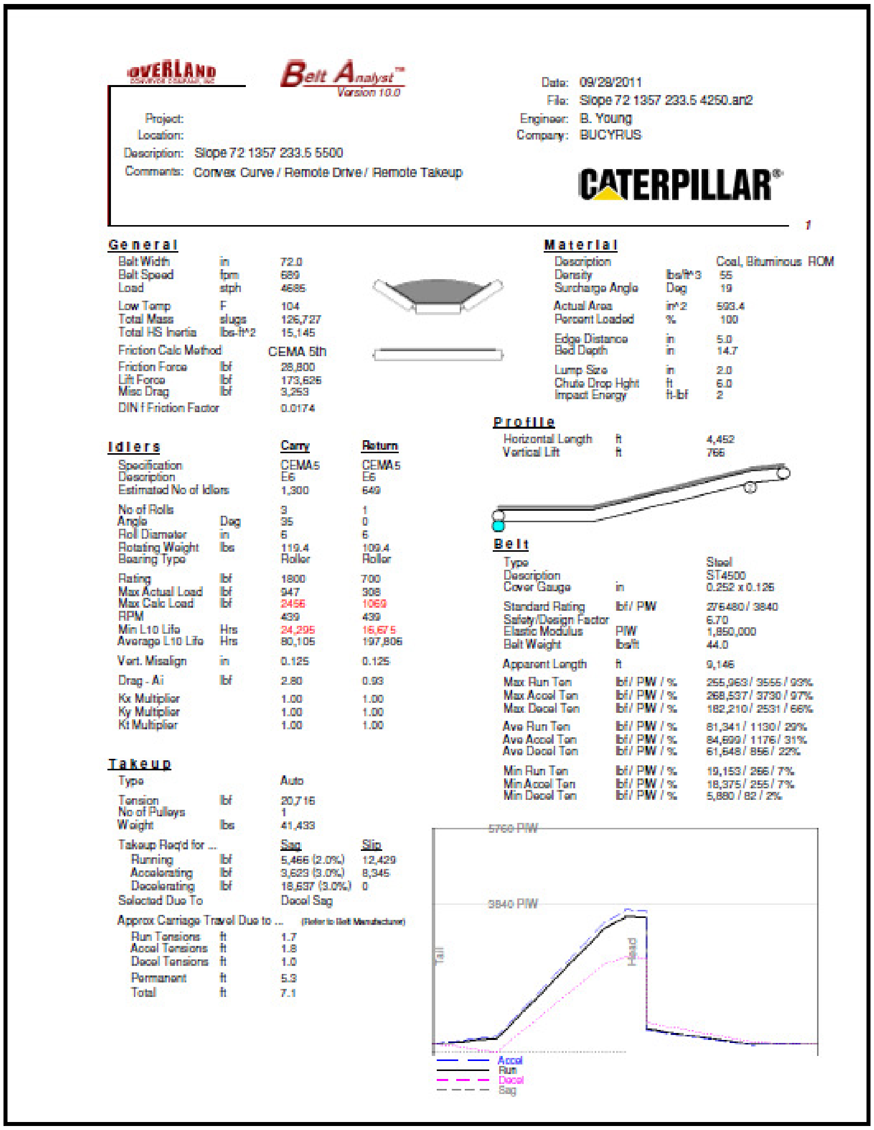

Figure 6. Belt Analyst Output for Option 3

Caterpillar Proposed Design

Based on the preliminary design review, the only viable option is Option 2. To review, the design specification for Option 2 is a 72” belt width with a capacity of 5,500 mtph (6,063 stph) at 4.5 mps (917 fpm). From Figure 5, the Belt Analyst™ summary shows that this option is capable of running 5,500mtph based on a 97% volumetric load capacity. Option 2 requires a total of 6,400 hp and a take up that can apply 15,453 lbf belt tension (or 30,906 lbf counterweight), when placed at the bottom of the slope near the tail. The belting requirement is a steel cable ST4000 belting that has a rating of 3,411 PIW. The overall horizontal length of this conveyor is 1,111m (3,644 ft) which includes a vertical curve with a 1,251 m (4,104 ft) radius at the bottom of the slope.

Caterpillar conducted a formal conveyor design project with the following objectives: 1) reviewing the three design options provided to the operator by the EPCM to determine their viability, and 2) providing the operator with an optimized slope conveyor design that meets their design criteria. Table 2 presents the data from this design project. As already stated, Option 1 and 3 are not viable due to insufficient capacity for both options. Therefore the design optimization focused on Option 2.

Table 2: Caterpillar Slope Design Data

			60" Belt Width			72" Belt Widtch					
			650 TPKL	866 TPKL	780 TPXL	650 TPKL	866 TPKL	780 TPXL	650 TPKL	866 TPKL	780 TPXL
		Belt Width	60"			72"					
		Length	1086 m			1357 m			1111 m		
		Lift	233 m								
		Belt Speed	4.5 mps			3.5 mps			4.5 mps		
		Desired Tonnage	5,500 mtph								
		Allowable Tonnage	3,750 mtph			4,250 mtph			5,500 mtph		
Drive		Main Drive Config	4 x 1100 HP		2 x 2200 HP	4 x 1300 HP		2 x 2600 HP	4 x 1600 HP		2 x 3200 HP
Drive		HS Coupling	650 TPKL	866 TPKL	780 TPXL	650 TPKL	866 TPKL	780 TPXL	650 TPKL	866 TPKL	780 TPXL
Drive		Backstop	BC-375MA			BC-540MA					
Drive		Motor Speed	1800 RPM	1200 RPM		1800 RPM	1200 RPM		1800 RPM	1200 RPM	
Drive		Total Horse Power	4400 HP			5200 HP			6400 HP		
Drive		Voltage	4160 V								
Drive		Drive Pulley Diameter	48"			54"					
Take-up	Cylinder	Take-up Type	Cylinder								
Take-up	Cylinder	Location	Tail								
Take-up	Cylinder	Take-up Tension Required	11,015#			20,716#			15,453#		
Take-up	Cylinder	Max Take-up Tension	21,536#			21,536#			21,536#		
Take-up	Cylinder	Max Line Pull	43,072#			43,072#			43,072#		
Take-up	Gravity	Take-up Type	Gravity								
Take-up	Gravity	Location	Drive								
Take-up	Gravity	Take-up Tension Required	46,187#			65,268#			59,174#		
Take-up	Gravity	Take-up Weight	92,374#			130,536#			118,348#		
Take-up		Take-up Pulley Diameter	36"			42"					
Belt	Cylinder	Cylinder TU Belt Suggested	ST3500			ST4500			ST4000		
Belt	Cylinder	% Running Belt Rating	97%			93%			97%		
Belt	Gravity	Gravity TU Belt Suggested	ST4000			ST4500			ST4500		
Belt	Gravity	% Running Belt Rating	91%			99%			93%		
Belt		Belt Cover Thicknesses	.25 x .125								
		Discharge Diameter	48"			54 "					
		Tail Pulley Diameter	36"			42 "					

Caterpillar first must consider the take up type and location for this slope conveyor. Since the preliminary design included a gravity take up, this option must be evaluated. A gravity take up is an economic way to maintain proper tension in a conveyor. There are two primary advantages of a gravity take up: 1) when applicable, it is the lowest cost take up option, and 2) it requires very little operational control once it is installed. Based on the data in Table 2, a gravity take up located on the surface (inby the drive) would require a counterweight of 118,348 lbf (59.17 tons). This size counterweight is really not practical and would be unsafe to work around and maintain. To fully evaluate a gravity take up option, one must consider locating the take up at the bottom of the 15.75° slope. This would require the take up to travel along the slope instead of vertically as on the surface. In this configuration the gravity take up would require a counterweight of 114,640 lbf (57.32 tons). Again this amount of weight is not practical and would be especially difficult to maintain underground. Therefore, based on the reasons given, a gravity take up at any of the locations discussed would not be a viable option.

Locating the take up at the bottom of the slope would greatly reduce the amount of tension required. From Table 2, a hydraulic cylinder take up located at the bottom of the slope requires a take up tension of 15,453 lbf. The data also show that a hydraulic take up located here has the advantage of allowing the operator to use ST4000 belting instead of ST4500, when compared to the gravity take up option. This is a significant cost savings that would offset the additional cost of the hydraulic take up versus the gravity take up. Another advantage is that a hydraulic take up has better response control when the operating conditions of the conveyor changes. This will reduce wear and tear on the belting during the day-to-day operation of the conveyor.

The next design consideration is the type of drive assembly for the slope conveyor. In the preliminary design, the EPCM proposed a four pulley drive arrangement. As stated earlier, a four pulley drive arrangement has been a common design for a slope conveyor, and the primary reason for this design is that it allows less belt slippage due to driving only on the clean side of the belt. However, as mine operations become more aware of the benefits of preventative maintenance programs, the focus has shifted to properly maintaining the belt using belt cleaners, thus it has become unnecessary to drive only the clean side of the belt. The alternative to this design is a two pulley drive assembly layout. A two pulley drive is the more economical design because it uses two fewer drive pulleys, as well as a much smaller drive frame. Another benefit of the two pulley design is the ability to move the drive assembly closer to the portal of the slope thereby eliminating the need for a high tension bend pulley. In a four pulley design a high tension bend pulley is required to properly transfer the belt into the drive from the head. As shown in Figure 7, a two pulley drive design located near the portal allows for proper belt transfer into the drive while maintaining the required 210° of belt wrap on the drive pulleys. While a low tension bend pulley is still required inby the drive to transfer the belt down the 15.75° slope, being able to eliminate the more expensive high tension bend pulley is another economic advantage for the operator.

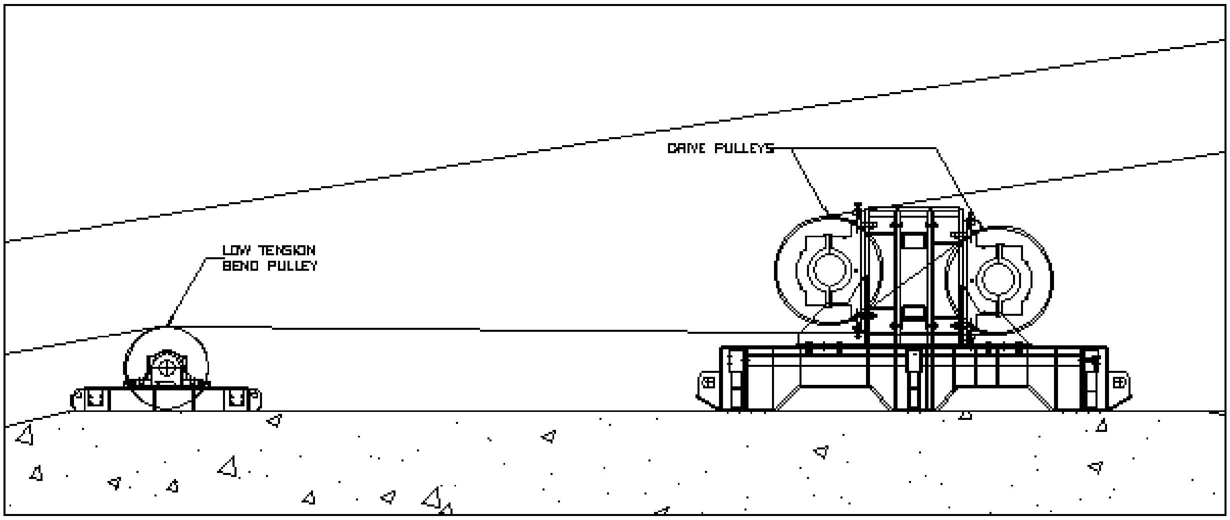

Figure 7. Caterpillar Proposed Two Pulley Drive Layout

Another design consideration for the drive assembly is the drive arrangement. As shown in Table 2, a total of 6,400 hp is required for this slope conveyor. The two most practical design solutions are either a dual drive design (2x3200 hp) or a quad drive design (4x1600 hp). There are advantages and disadvantages to both options. The largest advantage to the dual drive design over the quad drive design is economical. Even though the quad drive design requires smaller sized components (from a horsepower perspective), it is still more expensive to provide four 1,600 hp power modules compared to two 3,200 hp power modules. However this advantage also is the biggest disadvantage from an operational standpoint. In the event that a power module is taken out of service, due to a maintenance issue or simply routine service, the total power available is reduced by ½ in a dual drive design, but is only reduced by ¼ in a quad drive design. So in this case the total power for the dual drive design would be reduced to 3,200 hp, where the quad drive design would still have 4,800 hp available for operation. In this scenario, this mine's production would be reduced from 5,500 mtph to 2,750 mtph for the dual drive design, yet for the quad drive design would only be reduced to 4,125 mtph. For instance in a market where the mine can sell its coal for $100 per metric ton, operating at half capacity will cost the mine $137,500 more per hour than running at three quarter capacity . The greater upfront cost will more than pay for itself in the long run in lost capacity alone. Since this slope conveyor will service a longwall mine with multiple panels for more than 20 years, Caterpillar recommends a quad drive, dual pulley design due to higher reliability and availability.

It should be noted that Caterpillar would have also considered various drive technologies, such as variable frequency drives, but the operator specified using fluid coupling type drives only. From Table 2, one can see that several fill control fluid couplings were evaluated at both 1800 rpm and 1200 rpm motor input speeds. Using this data, as well as working with the fluid coupling vendor, it was determined that the best coupling for this application is a 650 TPKL for the 4x1600 hp drive design, which will use a motor speed of 1800 rpm.

Figure 8 shows the Caterpillar proposed slope design. In comparison to the preliminary design slope layout drawing shown in Figure 1, the two most significant differences are: 1) the hydraulic cylinder take up located at the bottom of the slope versus a gravity take up on the surface, and 2) a two pulley drive design located closer to the portal versus a four pulley drive design.

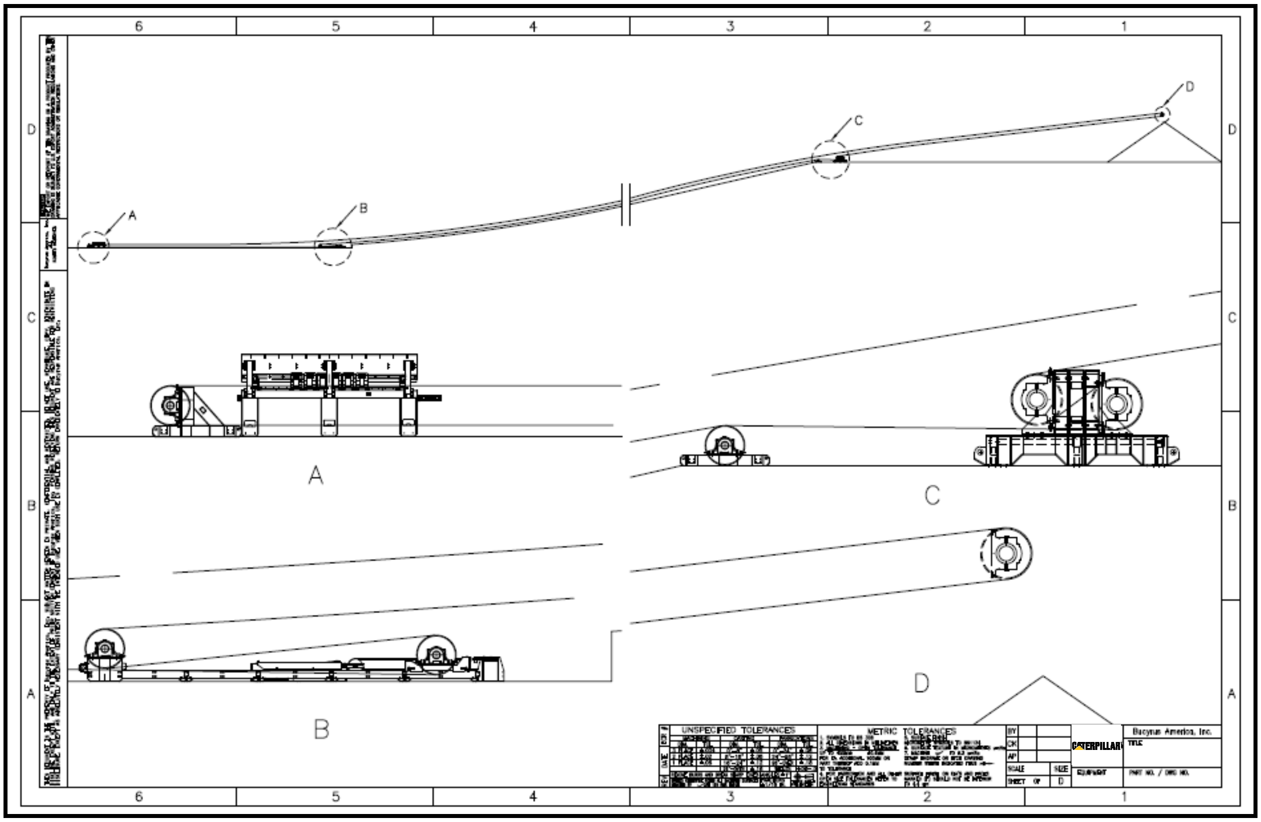

Figure 8. Caterpillar Proposed Slope Design

Technical Presentation at the Mine Site

Caterpillar prepared a technical report that included the evaluation of the three design options requested by the operator, as well as the proposed slope design. Once the operator had the opportunity to review this report, a meeting was scheduled to discuss these results. This meeting included the Mine Design Engineer, Engineering Manager, Mine Manager, Mine Maintenance Manager, and Material Handling Manager from the mine. Participants from Caterpillar included the Sales Representative from the local dealership, Regional Sales Manager, Belt Systems Product Group Project Engineer, and Belt Systems Product Group Product Manager for North America.

A brief presentation was given by Caterpillar to discuss the preliminary design review of the three design options provided by the EPCM. Even though Options 1 and 3 were not viable because they could not meet the 5,500 mtph load capacity criteria, it was important to show the operator what tonnages these options were capable of running. Once the operator viewed these results, they were in agreement that these options were not viable and thus were eliminated from consideration. Option 2 became the design specifications for this slope conveyor. For review, these specifications are a 72" belt width operating at 4.5 mps, conveying 5,500 mtph of ROM coal. The total horizontal length of this slope conveyor is 1,111m which includes a vertical curve with a 1,251 m radius at the bottom of the slope.

Once the general design specifications for the slope conveyor had been agreed upon, it was possible to discuss the details of this design. Caterpillar then presented their review of the preliminary slope layout drawing (Figure 1). The issues regarding the gravity take up located between the drive and discharge were discussed, and the operator quickly agreed that this would not be practical. However, the operator wanted to further discuss the possibility using a gravity take up located inby the drive. It was explained that even directly inby the drive, the counterweight would still be very large. The operator agreed that this also was not practical. Caterpillar then presented its recommendation to use a hydraulic cylinder take up located at the bottom of the slope near the tail. At this location the required take up tension would need to be 15,453 lbf. The operator agreed with this recommendation and decided to incorporate it into the design specification.

Next, Caterpillar presented its recommendation to use a two pulley drive versus the four pulley drive. Also, it was shown that locating the drive closer to the portal would eliminate the need for a high tension bend pulley (Figure 7). The operator understood the lower cost of a two pulley drive; however they were concerned that this design would be prone to belt slippage. Caterpillar then showed several examples where a two pulley slope drive has been successful. Also with the proper use of belt cleaners at the head, as well as ceramic lagging on the drive pulleys, belt slippage was less of a concern. The operator was convinced that a two pulley drive was viable and decided to go with this design. They also agreed that placing the drive closer to the portal was the most optimum location and had the added advantage of eliminating the high tension bend pulley.

Lastly, Caterpillar presented its recommendation to use a 4x1600 hp drive arrangement. The operator questioned why this arrangement was recommended instead of a 2x3200 hp, and asked if there was a technical reason why a 2x3200 hp would not meet their requirements. It was explained that a 2x3200 hp would certainly meet the power requirement for this slope conveyor, and that from a cost perspective this design was more advantageous in comparison to the 4x1600 hp drive arrangement. However, Caterpillar expressed concern in the case where a power module is taken out of service and the total power available is reduced by ½ in a dual drive design, but would only reduced by ¼ in a quad drive design. The data was then presented that at full production, this mine would be reduced from 5,500 mtph to 2,750 mtph for the dual drive design, but only reduced the quad drive design to 4,125 mtph. Based on current market conditions everyone agreed that this would be very costly to the operator to lose this much production. From this standpoint it was easy to justify the extra initial capital cost with a 4x1600 hp drive arrangement.

At this point the operator asked that Caterpillar discuss how their design would accommodate two separate conveyors transferring ROM coal onto the slope conveyor. These conveyors would be transferring from different angles and different levels. This detailed information had not been disclosed up to this point so the Caterpillar representatives asked to review the mine layout maps to better explain this scenario. The operator presented the mine maps and explained that two longwall panels would be operating simultaneously but in different coal seams. The seams will be at different vertical depths underground, meaning one seam will run above the other. With this information Caterpillar acknowledged that a single tail loading section would not be applicable. It was recommended that the operator use an A-frame tail assembly with either an extended intermediate loading section or two separate intermediate loading sections. This would allow for a sufficient amount of impact zone to efficiently transfer coal from two separate conveyors. In order to properly design chutes to handle the transfer of two belts at different angles and elevations, discrete element modeling (DEM) will be needed to model these transfer points. Once the DEM modeling is completed, Caterpillar could design this transfer chute arrangement and present it to the operator. It was agreed that DEM modeling would be included in the official request for bid package and that each bidder would have to supply their recommended design based on these results.

The operator concluded the meeting stating that they were very pleased with the efforts from Caterpillar's efforts to optimize the slope conveyor design and better define its specifications. They also stated that this would make evaluating the bid packages much easier due to the fact that there would be less room for interpretation by each bidder. Caterpillar was also asked supply a budgetary quote based on the agreed upon design specifications so they could revise their capital expenditure budget for this project.

Conclusion

Designing a new underground longwall mine is a large project that involves many people. The primary objective of this project is to design the most safe and efficient operating mine with regards to coal production. An important aspect of the mine design is how the coal will be transported to the surface. All coal that is mine at the operating face eventually must be transported to the surface via the slope conveyor. A slope conveyor could be considered the most important piece of equipment in a mine since it does serve as the "lifeline" of the mine. Unfortunately the slope conveyor is often overlooked during the design phase of the mine. Even though a slope conveyor is expected to have an availability of over 98%, little is done to optimize its design.

In 2011, during the design phase of a new underground longwall mine in Mexico, the operator realized that the preliminary slope conveyor design provided by the contracted EPCM may not be the optimal design. Therefore, they decided to contact Caterpillar, a conveyor system OEM, to request a technical review of the preliminary slope conveyor design, and then collaborate with them to determine an optimal slope conveyor design that they could use for the official request for bid package. This was an atypical approach to involve the conveyor OEM at this stage of mine design; however the operator determined this would provide them with a design that would allow them to better evaluate future bids, and hopefully decrease the amount of time needed to review the bids.

Caterpillar reviewed the three design options (Table 1) and the preliminary layout drawing (Figure 1). Based on this review it was determined that Option 2, with a 72" belt width operating at 4.5 mps would provide the required 5500 mtph load capacity. In review of the preliminary layout drawing there were two significant issues: 1) location of the gravity take up between the drive and discharge, and 2) the use of a four pulley drive design. Caterpillar took exception to these items and recommended a slope conveyor layout shown in Figure 8. This is a 72" 4x1600 hp conveyor with a two pulley drive design and a hydraulic cylinder take up located at the bottom of the slope close to the tail. A technical report was prepared and provided to the operator for review.

A meeting was held at the mine site between the operator and Caterpillar to discuss the results of the review. This collaborative effort concluded in an agreed upon slope conveyor design that is believed to be an optimal design. The operator was very pleased with the outcome of this effort and will use these design specifications in their official request for bid package. The value of collaborating with a conveyor system OEM was realized by the operator and they feel confident that because of this collaboration not only will the bid process be more efficient, eventually the slope conveyor that is installed will be optimally designed to meet the operating requirements over the life of the mine.