6.9 KM HORIZONTALLY CURVED TROUGHED CONVEYOR SYSTEM USING AN ELEVATED TRIANGULATED GANTRY

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INTRODUCTION

The Objana Cement Plant is located in central Nigeria, approximately 175km southeast of the capital city Abuja (figure 1). It is the second largest cement plant in Africa, and the fifth largest in the world [1]. The selected mining location is unique as it has all the major raw materials (except gypsum) in close proximity. This includes limestone, clay, marl, laterite soil, and laterite iron.

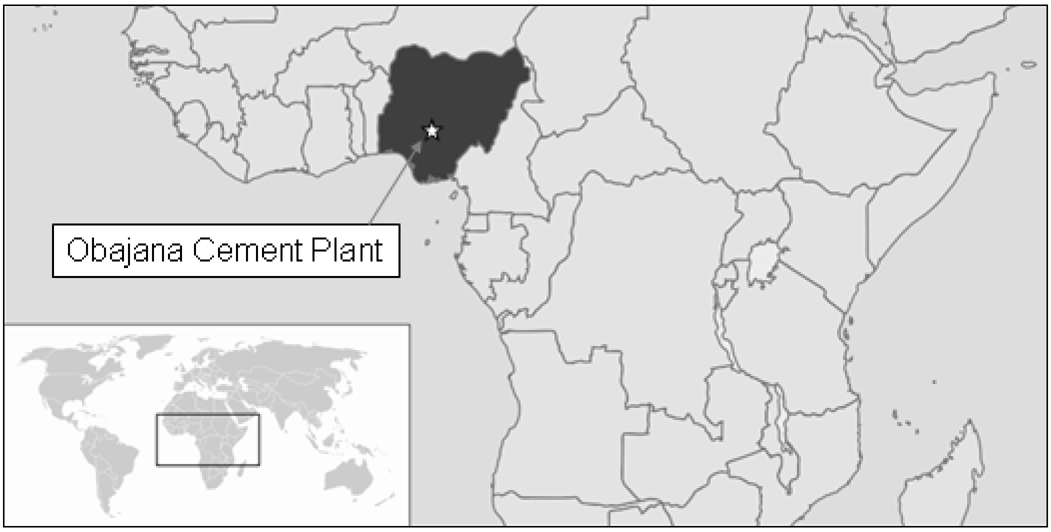

Figure 1 – Objana Cement Plant location in Nigeria

The plant has a capacity of 5 million metric tons per year (~15,000 tons per day). A 135 megawatt gas-fired power plant, with 90 km of natural gas pipeline, was constructed to power the plant. The total project cost is approximately 1.2 billion US dollars.

The lifeline of this plant is two overland conveyors totaling 7.7km in length. The first 800m conveyor is relatively mundane. The second conveyor however, is unlike any other troughed belt conveyor in the world. Its 6.9km length transports 2,400 T/H of material, and operates at 5.0 m/s. Its "snake" profile consists of 11 vertical curves, and four main horizontal curves. Overall, 70% of the total conveyor length is located within one of the horizontal curves. The last of which is 2,000m in radius, has an arc length of 2.2km, and is located at the high tension head end of the conveyor. Although these specifications are noteworthy, the exclusivity of this system is that it is entirely elevated from head to tail using a unique triangulated truss gantry structure (figure 2).

Figure 2 – 6.9km overland conveyor, which is entirely elevated using a triangulated gantry

The author has been fortunate enough to have designed, and visited, many of the most unique overland conveyor system around the globe. This system however, is unlike any of them. Although the elevation of the conveyor was a client specification, its potential environmental benefits are obvious. As overland conveyors have become longer, and their ability to transverse difficult areas and terrains improves, they will inevitably become more environmentally unfriendly. By elevating the conveyor system, wildlife and/or livestock can freely pass underneath (figure 3). And, as will be discussed, there are numerous other advantages as well.

Figure 3 – Local villagers and livestock can pass freely under the conveyor structure.

BACKGROUND INFORMATION

Fully elevated conveyor systems are not a new concept. Furthermore, the triangulated gantry concept had been used on a small, low tonnage, pipe conveyor system [2]. However, unlike a confined pipe conveyor, a conventional trough conveying, 6.9km in length, with multiple horizontal curves, was well beyond any existing conveyor design in the world and thus required a number of innovated design ideas.

Exclusive Technical Services (ETS) was awarded the contract for the engineering, and procurement of the conveyor system. ETS has since been purchased by Sandvik Materials

Handlings. However, this project was completed under the original ETS banner. The conveyor design, static and dynamic analysis, and control philosophy was completed by the author.

Before the conveyor contract was issued, the client had already constructed a major haul road between the plant and mine. The routing of a road however, is dictated by an entirely different set of criteria than an overland conveyor belt. Nevertheless, the client strongly preferred that the conveyor follow the road as closely as possible, and therefore this was one of the early design challenges.

A number of different conveyor routes were investigated. Originally, three conveyors systems were envisioned. The first conveyor would transport material from the mine to the road. The second conveyor would then follow the road as close as possible, with a third conveyor then feeding into the secured plant area. These conveyors were at approximately right angles to one another.

After further investigation, it was determined that the second and third conveyors could potentially be combined (figure 4). This combination required the conveyor to be run slightly faster than originally proposed. However, in addition to eliminating an entire transfer point and separate conveyor, this option had other major benefits. The first conveyor could be driven from the tail end while the second conveyor was driven from the head. The transfer point would therefore not require any major mechanical or electrical equipment. This was a significant benefit to the client in terms of conveyor security and maintenance, and thus an ideal solution if it was indeed possible.

Figure 4 – 2,000m horizontal curve eliminated a transfer point by combining two conveyors

CONVEYOR DESIGN ISSUES

The design of this conveyor however was anything but straightforward. Combining the second and third conveyors required a very tight horizontal radius, which had an arc length of 2.2 km. Additionally, the conveyor had to dip down to cross over a river 1.8km into the curve (~900m from the head end). The concave curve in this region, combined with the already tight horizontal curve, made the engineering design particularly complex.

In order to maintain acceptable belt tracking in the horizontal curves, the tensions needed to be kept as low as possible. Although this could be achieved under normal operational conditions, dynamic problems arose in the event of a power outage. When power to the motors is lost (which happens quite frequently in Nigeria), the belt tension differential across the driven pulleys is also lost. This results in a collapsing tension wave, which travels along the carry side of the conveyor. On this system, this tension wave would have resulted in unacceptably low tensions, excessive belt sag, and material spillage.

Normally, the designer could increase the take-up tension to compensate for this effect. However, due to the horizontal curves this was not possible. This would have also resulted in a higher belt rating, and therefore had commercial disadvantages.

Another option would have been to move one of the motors to the tail of the conveyor. In this case, the take-up tension can be increased, while maintaining the same carry side tensions. When power is lost, the high-tension side of the tail drive actually increases the carry side tensions. Combined with the higher take-up tension, this would have resulted in an acceptable design. Unfortunately, due to the transfer point security issues, having a drive at the tail end of the conveyor was not desirable. This arrangement would also have resulted in a significant increase in cost.

However, the dynamic benefits of the tail drive concept, could still be achieved using a drive / take-up / drive arrangement at the head end. This layout kept all the major components at the head, while providing many of the dynamic benefits of a tail drive system. For many conveyors this is an ideal arrangement. Unfortunately, there is one major drawback when placing the take-up system between the drives. This is the fact that the return side belt tensions will vary with the loading of the conveyor. This is a significant concern for the belt tracking in the already tight horizontal curves. Properly designing the return side of the belt to track at a given tension is one thing, but having significant steady state changes in these tensions is another. Furthermore, unlike the carry side of the conveyor (which has the material mass to counteract an increase in belt tension), the return side of the conveyor is always empty.

So how could the conveyor be designed to minimize the take-up tension, maintain acceptable belt tracking in the horizontal curves (carry and return), but yet prevent excessive belt sag and material spillage in the event of a power failure?

Fortunately, the conveyor designer has a number of "dynamic tuning devices" and which aid in such situations. One potential option is to add flywheels on the high-speed side of the reducers. When power is lost, the flywheel inertia continues to drive the system and prevents the belt tensions from immediately collapsing. This, in effect, "smooths" out the dynamics of the conveyor. Flywheels are very useful on many conveyors. However, on this particular conveyor, even the largest of flywheels were insufficient to maintain acceptable belt tensions.

Another potential tuning device is using a brake at the tail. This could be applied during an emergency stop, thereby increasing the carry side tensions. Even a very large brake however was insufficient to prevent the low-tension dynamic effects from occurring. Additionally, belt slippage on the brake pulley would have occurred on even a small brake and a ceramic lagged pulley.

Although a single flight option began looking less feasible, a simple solution was found using a capstan brake on the take-up [3]. This device locks the take-up carriage in its current position, not allowing it to move. Normally in the event of a power failure, the take-up would move and "absorb" the motor tension differential. With a capstan however, the now fixed take-up maintains the total overall tension in the conveyor system. The resulting effect is significantly higher belt tensions (in the low-tension zones) during stopping. Figure 5 shows the capstan brake installation.

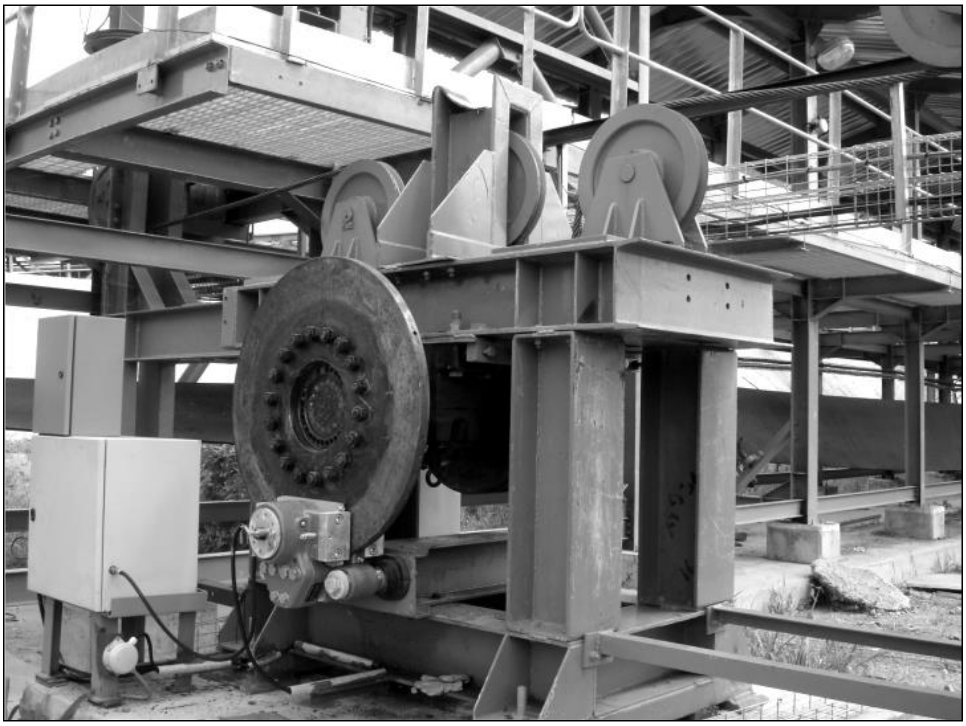

Figure 5 – Capstan brake between the counterweight mass and take-up pulley

On this conveyor, the higher belt tensions were more than enough to maintain acceptable sag levels. One drawback to this design however is that the return side tensions will also increased during stopping. This however could be taking into account when designing the idler banking angles, side guide rolls and other mechanical items.

TAIL BRAKE

The conveyor profile has several decline sections. One particular section drops approximately 40 m. If this area is loaded with material the belt could drift for up to 90 seconds in the event of a power failure. If the head end of the conveyor were also loaded a substantial amount of material would build up at the discharge transfer point. To reduce the stopping time during a power failure (or emergency stop) a small 20 kN*m brake was added. Ideally, it would have been convenient for this brake to have been placed at the head end of the conveyor. However, it would have resulted in higher return side tensions. Therefore, the brake was placed on the tail pulley. Although the initial hope was to eliminate any equipment at the transfer point, this brake was considered acceptable. Additionally, since 3 phase power was already available for lighting, and PLC signals for the plugged chute and belt rip detection would be required in any case, the additional cost was minimal.

3-ROLL RETURN SIDE IDLERS

To help control belt displacement, a three roll idler set was used on the return side of the conveyor. Although this configuration is not common, the result was exceptional. The use of a 3-roll return set increases the longitudinal stiffness of the belt. Therefore the belt flap and resonance is typically much better than a conventional two-roll VEE return. Furthermore, the idlers can be pitched farther apart, which offsets the cost of additional rolls. For example on a conveyor with a 4 m VEE return spacing, a three-roll set could use 6 m. Therefore the same number of rolls is required, but fewer idler frames. In fact, with a 20-degree troughing angle, the overall idler bearing L10 life is actually greater on the longer 3-roll spacing.

BELT TURNOVER

Belt turnovers were also installed on the system. The turnovers served three distinct purposes:

1. To keep the return side idlers clean. This increases the idler life and reduces maintenance and belt vibration.

2. To prevent excessive fatiguing of the belt at the idler junction joint due the three roll return idlers.
3. Reduce the belt tensions. The belting incorporated a low rolling resistance rubber compound on the bottom belt cover, which would be in contact with both the carry and return side idlers.

OVERALL

In the end the final conveyor profile and layout is shown in Figure 6. The selected belt was 1200 mm wide, with a rating of ST-1200 N/mm. Three 500 kW, variable frequency motors were installed (two on the primary, and one on the secondary drive pulleys).

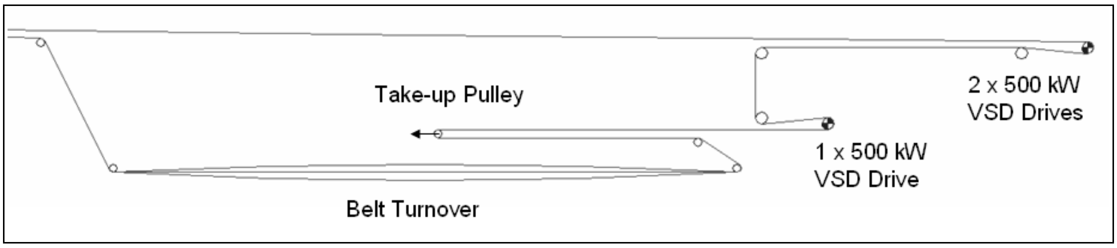

Figure 6 - Final drive and pulley arrangement at head end

STRUCTURE

Concrete columns were used as cement was readily available very close to the site. The columns were cast on site, thereby saving on transportation costs. The casting operation also created much needed employment for locals. Furthermore, they were 40% less then the price of an equivalent fabricated steel unit, even before transportation costs were taken into consideration.

The tubular structure allows greater spans when compared to conventional profile steel design. In this instance the span was 36m allowing for the tubular steel members for 3 gantries to be fitted into a 12m container. The three apexes of the triangle tubular beams were welded on site. The rest of the tubular structural beams were bolted together thus keeping welding on site to a minimum. The tubular space frame structure is significantly lighter than a conventional elevated design. This resulted in a considerable cost saving not only in the cost of steel, but also in transport. The structural elevation above the ground varied from 6m to 12m (figure 7).

Figure 7 – Concrete structural supports

Another inventive idea was to hang the return side idler set below the gantry in order to minimum its size. However, the structure still needed to be large enough to achieve a continuous vertical and horizontal conveyor path thru each “straight” gantry section. This required a series of standard brackets and attention to detail. Here again, the added pre-assemble effort was well worth the effect. In the end almost 200 individual gantry sections were assemble on site. Of this not one was damage, or required a single alteration.

The concrete foundations were pre-cast and supplied by the client. On future systems a steel support structure would most likely be used to reduce the cost. The foundation bases were 3m x 3m and assembled in four parts depending on the elevation requirement. Each gantry section was then lifted onto the supporting foundation, and bolted in place.

A final obstacle for the conveyor system and gantry design was a 50 m river crossing. In order to supply water to the plant, a dam and large reservoir was created. However, during the rainy season the dam spillway, and resulting water flow was not trivial. The triangulated gantry design however implicitly lent itself very well to meet this requirement. The main upper gantry structure was left unaltered with an increased support bracing added underneath (figures 8 & 9).

Figure 8 – River crossing during construction (dry season)

Figure 9 – River crossing completed (rainy season)

TROLLEY DESIGN

In order to provide easy access and maintenance to the conveyor, two trolleys were designed and engineered by ETS (figure 10). The design of these units proved to be a challenge as no data was available on similar designs of this nature. Comprehensive testing was done to establish actual loading requirements; tire indention loses, and power requirements. What was initially thought to be a straightforward design, ended up requiring a significant amount of forethought, engineering optimization, and full scale testing.

Initially it was perceived that a pneumatic tire would be ideal for the application. Requiring a pneumatic tire to run on a tubular member turned out to be unacceptable. There was excessive deflection of the tire under the loaded condition and the tire moved inside the rim during testing.

Discarding this approach, the alternative of using liquid filled tires was pursued. The deflections measured under load were adequate relative to the pneumatic units and it was thought that the problem was solved. However, the liquid filled tire developed an indentation memory with the unit standing overnight and this approach had to be discarded.

Solid tires then became the only way forward. To everyone's amazement the first flat bottom solid tire running on a tubular surface took only 20 minutes to burst. In the end, a solid tire profiled to the tubular member achieved the required engineering result and was selected.

Having resolved the tire issue, the rolling resistance was measure and the drive train sized accordingly. In order to prove the design, one gantry section was erected and the trolley unit tested on the installation. The gantry was purposely kinked to simulate the curved conditions on site. It was set at the maximum incline angle that was expected on site, and then further increased by 2 degrees to allow for a head wind condition and other factors (figure 10). The tests conducted proved that the system was adequate for the duty thus confirming that it could be released for delivery to site.

Figure 10 – Trolley test installation on elevated gantry

Each unit uses a diesel engine to power a variable speed electric motor and drive the trolley. The motor control included a very smooth acceleration and declaration ramp with an adjustable speed range from 0.1m/s to 2.5 m/s. The trolley needed to be capable of climbing (and descending) slopes up to 10 degrees. In order to have safe, and easy access to the conveyor for maintenance, fold down platforms were installed on each side.

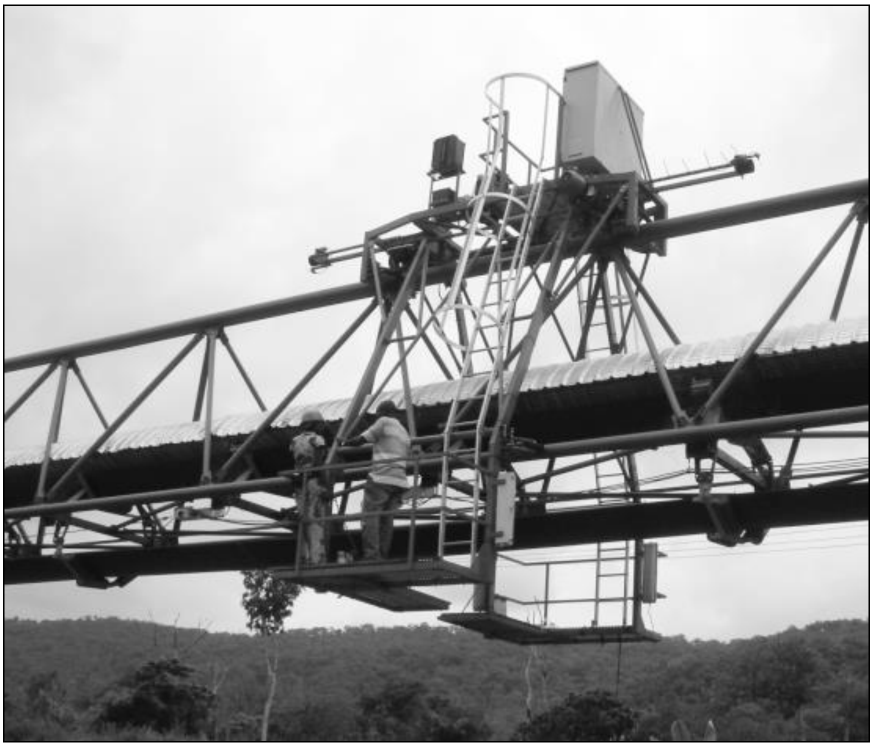

Figure 11 – One of two maintenance trolleys in operation

The final trolley design resulted in a unit, which makes maintenance a breeze. Traditionally, a maintenance issue on overland conveyors is simply identifying stuck or failed idler rolls. On many systems the conveyor is only easily accessible from one side (typically a maintenance road) and thus physically seeing the return side idlers is not always easy. With the maintenance trolley a person can simply ride along the conveyor (either side) and closely look for any problems with the belt, structure, or idlers (figure 11).

COSTS

Comparing the tubular elevated gantry to ground strung stringers of conventional profile structures, the latter will be 110kg/m lighter. However the advantages of an elevated system are obviously lost. Taking the ground profile and the civil works into account, this savings could very quickly be eroded. This is particularly true if the terrain is very undulating and requires significant earthworks and civil engineering (these requirements are substantially reduced on an elevated system). An often overlooked cost benefit is the fact that road and people crossings have to be provided on ground based systems.

DRY COMMISSIONING

Dry commissioning of the conveyor took place in the fall of 2006. The conveyor was fully instrumented with data acquisition equipment to verify that it met the original design specifications [4, 5, 6]. All motor and brake shafts were instrumented with strain gauge telemetry equipment, and a load cell was installed on the cable reeving of the take-up carriage.

The commissioning of any conveyor with VSD drives is truly a pleasure compared to fluid coupling and other types. After performing a direction check, the conveyor was started and brought to 0.25 m/s speed for about a minute. After communications from the head, tail and various horizontal curve locations all report no problems the system was restarted at 0.5 m/s and allowed to run. Within a few minutes the belt began to mistrack on several of the pulleys. The system was stopped for the day, and each of the mistracking pulleys was packed on the required pillow block. In the following days the pulley tracking issues were resolved along with minor turnover modifications. Once the system was tracking at 0.5 m/s the speed was gradually increased to 5 m/s in step intervals. To the authors delight, not a single idler frame was adjusted. The belt was tracking exceptionally well, particularly in the horizontal curves.

At this time however, there were several issues happening in the rest of the plant and material was not available. Although a few minor PLC and interlock issues remained, the system was mechanically functioning exceptionally well. At this point the field measurement equipment was removed and stored awaiting the authors return.

WET COMMISSIONING

Presently, the system is operating at material surges up to 2000 T/H. According to the mine the conveyor has been operating exceptionally well. The author is scheduled to return to the mine for fully loaded wet commissioning within a few weeks of the writing of this paper. At that time a full set of field measurements will be obtained on the conveyors power draw, dynamic characteristics, capstan operation, and belt tracking of the horizontal curves. This information will be used to design and engineer the next generation of conveyor systems.

ACKNOWLEDGEMENTS

The structural design for this system received the 2005 South African steel export award for engineering excellence in the use of steel.

CONCLUSION

This paper has discussed various design features for a new type of overland conveyor system. It showed how thoroughly investigating different design options resulted in the ability to combine multiple conveyors into a single flight. This not only resulted in significant cost savings, but also in increased system reliability, lower maintenance, and many other benefits.

The elevated triangulated gantry resulted in a more secure conveyor, with enormous potential for more environmentally friendly designs. After construction the surrounding area will return to its natural habitat as there is no required maintenance road. This system allows for free movement of cattle, wild animals, and people. Furthermore, both the conveyor equipment, and the product itself, are safe from theft and pilferage. This is especially important if the material being conveyed is valuable, or when system security is a concern. Additionally land acquisition rights, and other common overland conveyor obstacles may be more easily overcome using this type of friendly structure.

As this system proves, with good engineering and attention to detail, we can continue to expand the limits of current overland conveyor technology in a safe, reliable, and environmentally responsible manner.

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