CABLE BRIDGE CONVEYOR: NEW SUSPENSION BRIDGE BASED CONVEYOR SYSTEM

Yijun Zhang, Cable Bridge Conveyor, LLC., Bellingham, Washington

Abstract

Above ground, elevated belt conveyors with span >200m between support points can cross valleys, rivers, forests and buildings with minimal footprint. The Cable Bridge Conveyor is a new type of suspension bridge based belt conveyor system that has long span between support points. It combines typical belt conveyor and the improved simple suspension bridge to form a conveyor bridge. The improved simple suspension bridge places a widened bridge deck directly on suspended cables, without the need for high truss towers. The benefits include reduced cost and increase aerodynamic stability compared to conventional suspension bridges. The Cable Bridge Conveyor's compatibility with current belt conveyors allows the versatility in application.

Introduction

Belt conveyor is a ubiquitous material handling system. Conveyors can be placed directly on ground or elevated above ground by support structures. Considerations of cost, design, environment, civil work, safety and process requirements are all factors in choosing the ground based or elevated conveyors (1). The ground based conveyor has the lowest structural cost, where the conveyor is laying on an existing road. Maintenance access is easy and straight forward. Compared to the ground based conveyor, the elevated conveyor can cross existing buildings and structures, give passage to traffic beneath the conveyor, has smaller footprint, and requires less civil work to pass mountainous areas. The drawback of the elevated conveyor is higher structural cost, which can be compared with savings in civil work and other benefits. Conventional elevated conveyors are supported by rigid truss type structures, with typical span of 15m to 25m between concrete support bents or steel trestles. Triangular truss, using steel pipes instead of hot rolled steel sections, is more efficient. The typical span of triangular truss supported conveyor is around 30m to 40m, while the weight is about 10% less than conventional box truss with shorter span (2).

Long span elevated structure based on suspension bridge is another step forward in increasing the distance between support bents, reaching 100m~400m and beyond. The very wide distance between support points of an elevated conveyor offers unique benefits. The conveyor can cross rivers, valleys, highways, forests and other obstacles with minimal footprint and reduced civil work. The versatility from long span conveyors makes bulk material transportation over previously impossible terrains now a feasible option.

There are several types of long span elevated structures. Historically, conventional suspension bridge is used to support conveyors dated back in 1930s. It was then pioneered in the hydropower dam constructions in US west coast. One example is a suspension conveyor bridge crossing the Columbia River, Washington, during the construction of Grand Coulee Dam (3). The conveyor was used to transport aggregate across the river. The suspension bridge is continuously used in modern conveyor system when there is a special need of long span. **Figure 1** shows a suspension bridge that supports a 1600 T/H copper ore conveyor to across a deep valley in British Columbia, Canada. The bridge span is 404m, with 174m high truss tower to which the main suspension cables are attached (4).

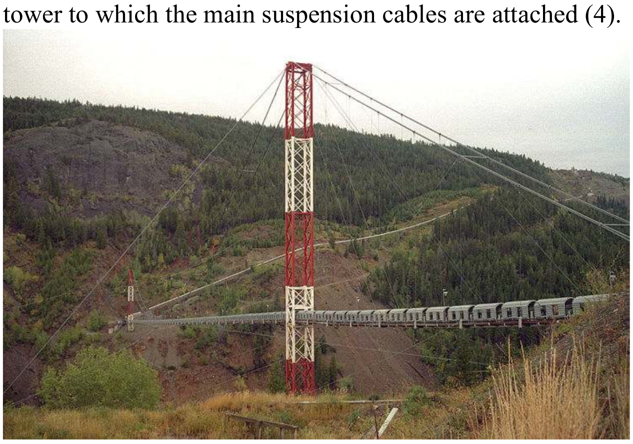

Figure 1. Similkameen Ore Conveyor Bridge in British Columbia, Canada

Conventional suspension bridge indeed can provide long span solution. The first drawback is the high truss tower, which is expensive to build and difficult to erect in difficult terrains. The second drawback is that the bridge has weak resistance against horizontal wind, because the bridge deck is hanging without lateral constraint from the main suspension cables. Additional stabilization methods or higher bridge deck stiffness are required to increase the wind resistance. The Tacoma Narrows Bridge is a well-known suspension bridge failure due to wind induced aerodynamic instability.

The Ropecon system from Doppelmayr uses a specially made belt with axles and wheels fixed to the belt and moving on suspended cables (5). Although the suspended cables have long span between support points, the special belt design is unique and not compatible with typical belt conveyors.

Improved Simple Suspension Bridge

The simple suspension bridge places the bridge deck directly on tensioned steel cables, instead of hanging the bridge deck below. This eliminates the high towers of conventional suspension bridge, to which suspended cables are attached. As a result, simple suspension bridge costs less and is easier to construct. This is probably the oldest form of suspension bridge practiced by mankind. The Cable Bridge Conveyor combines the Improved Simple Suspension Bridge and conventional belt conveyor. The Improved Simple Suspension Bridge utilizes a widened bridge deck to include edge cables at both ends. The center section of the bridge deck is used for traffic. The majority of tension-bearing steel cables are located at the center section. The bridge deck extends from the center section with extra width and has steel cables fastened at both ends of the bridge deck beam. An example of the improved simple suspension bridge is shown in **Figure 2**.

Figure 2. Improved Simple Suspension Bridge

The purpose of edge cables is to increase the bridge torsional stiffness and wind stability, because the edge cables increase significantly the moment against the twisting movement of the bridge deck around the center line, thus making the bridge more stable. The London Millennium Foot Bridge utilizes a very similar design to the improved simple suspension bridge (6).

Aerodynamic stability is the key limiting factor to long span suspension structures. This is well illustrated by the Tacoma Narrows Bridge collapse in 1940. **Figure 3** shows the torsional vibration of the Tacoma Narrows bridge deck due to harmonic wind vortex shedding (7). Compared to conventional suspension structures, the improved simple suspension bridge is designed to increase the aerodynamic stability by using wider bridge deck.

Figure 3. Twisting Motion of Tacoma Narrows Bridge

Over fifty improved simple suspension bridges were built during the last forty years. The typical bridge span is between 150m to 450m (8). Originally developed as a rapid –deployment suspension bridge by the military (8), this type of bridge was later used in hydropower dam construction sites to provide traffic access cross rivers (9-11). Because no high towers are needed, the lower cost and ease of construction are recognized as being superior to conventional suspension bridges, while maintaining the same functionality. Once the cable anchor foundation is finished, the bridge can be finished within a couple of months. In the mining industry, the improved simple suspension bridge has been used in carrying copper concentrate slurry pipeline to cross deep valley in Argentina (12).

Cable Bridge Conveyor

The Cable Bridge Conveyor (CBC) combines two well proven technologies: the improved simple suspension bridge and the belt conveyor. **Figure 4** shows the typical arrangement of Cable Bridge Conveyor. The belt conveyor can use the ground based, stringer type structure mounted on bridge deck beams by welded anchor bolts. The tensioned steel cables underneath bridge deck beams provide accurate self-alignment. A major benefit is that the conveyor structure and belt are seamlessly compatible with conventional belt conveyor technology. Singe span of CBC can be used as a segment of a long overland conveyor to overcome terrain obstacles, in which case the improved simple suspension bridge is a conveyor bridge. The entire conveyor can also be comprised of single or multi span Cable Bridge Conveyor.

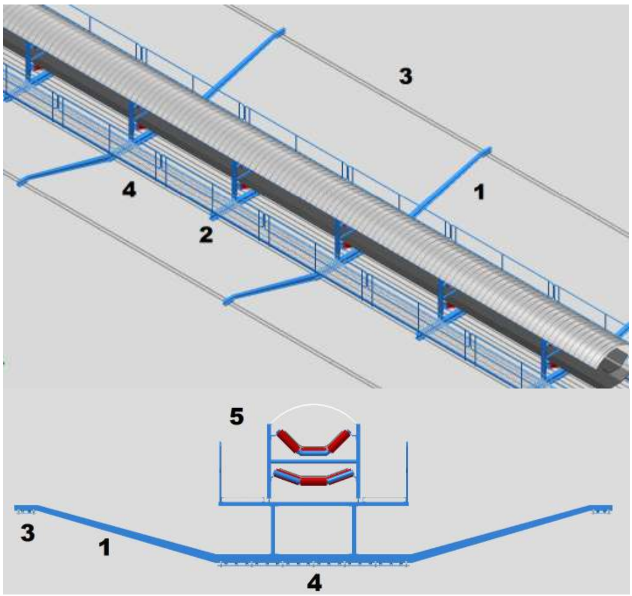

Figure 4. Cable Bridge Conveyor with Walkway: ISO View (top figure) and Cross Sectional Arrangement (bottom figure). 1: wide deck beam; 2: narrow deck beam; 3: edge cables; 4: center cables; 5: belt conveyor with walkway and hood cover.

The tensioned and suspended steel cables of the simple suspension bridge have a catenary curve shape (bridge line). The conveyor belt can follow the catenary curve approximately near the middle of the span, through a vertical concave curve (center of radius is above the curve). Near the support points at the ends of the catenary, the belt line has to transition to a vertical convex curve (center of radius is below the curve). This is because the bridge steel cables can go over the support points with much smaller convex curve radii than conveyor belt is capable of. This problem can be resolved by controlling the conveyor stringer height at each idler station to adjust the distance between the belt and the bridge, so that the conveyor belt can travel over the support points at allowable vertical convex curves. During the design stage, the bridge line and belt line can be calculated so that the conveyor stringer height can all be pre-determined.

Conventional walkway can be placed on either side of the CBC, to provide inspection and maintenance access. The conveyor stringer can also be adapted to include self-powered trolleys. With modern overland conveyor is extending beyond tens of kms in a single flight (13), walkway on elevated steel truss can be replaced by self-powered vehicle that travels on the conveyor structure and provides better maintenance access (14). For CBC, using self-powered trolleys without the walkway also reduces the structural load and helps save structural cost. In **Figure 5**, CBC is designed with a self-powered trolley instead of walkway. The figure also illustrates the gradual transition of the belt from a concave curve near the center of the span to a convex curve near the support point at the end of span, by changing the conveyor stringer height. Near the support end, the conveyor bridge suspension cables go over a different path compared to the belt.

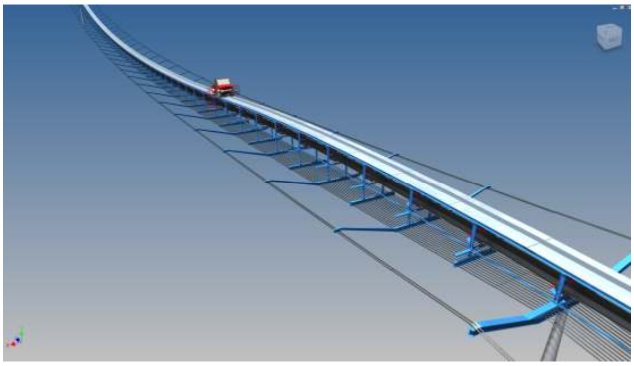

Figure 5. Cable Bridge Conveyor with Self Powered Trolley: Bridge line and Belt line

CBC can accommodate horizontal curves. This is done by widening the bridge center section, and placing the horizontally curved conveyor stringer along the bride deck beams. Under allowable belt tension and curve radius, horizontally curved conveyor doesn't cause significant disturbance to the CBC.

Static and dynamic finite element analysis are carried out during the design stage. **Figure 6** shows the sag of a 400m span Cable Bridge Conveyor. Typical sag ratio is 1/40. The tensions of steel cables under various load cases are calculated to ensure allowable safety factors are maintained. The bridge deck beam is analyzed for bending stress during the twisting motion when the edge cables and center cables have different tensions. Modal analysis is done on the CBC to calculate natural frequencies. For long span beyond 400m, the wind stability can further be analyzed in wind tunnel tests.

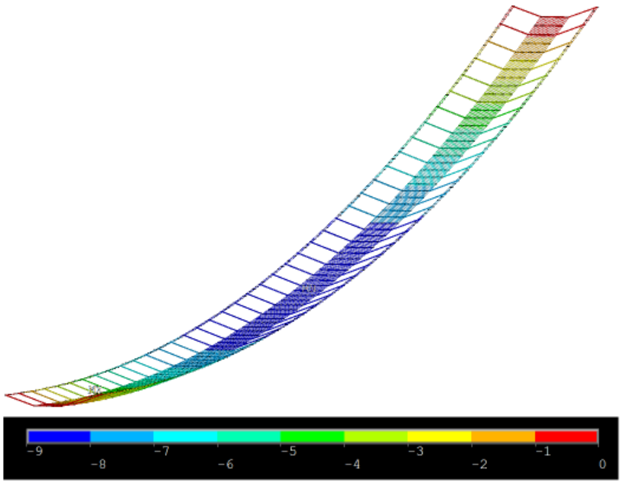

Figure 6. Finite Element Analysis of a 400m span Cable Bridge Conveyor, showing the vertical sag (m) under load.

Summary

Cable Bridge Conveyor combines two mature technologies: the improved simple suspension bridge and belt conveyors. Cable Bridge Conveyor offers the benefit of elevated belt conveyor with very long span between 200m ~ 400m between support points. The long span allows the belt conveyor to cross terrain obstacles and minimize the footprint on environment. The improved simple suspension bridge uses a widened bridge deck with stabilizing cables at both ends to increase aerodynamic stability. Construction time and expense are reduced by eliminating the high towers of conventional suspension bridges. Due to the compatibility of existing belt conveyors, single span or multiple span Cable Bridge Conveyor can be a segment or the entire length of the belt conveyor system.

References

1. Zhang, Yijun (2014), "Efficient Elevated Conveyor Structure and Better Maintenance using Self Powred Trolley" in *2014 Society for Mining Metallurgy & Exploration (SME) Annual Meeting*, Salt Lake City, Utah
2. Jennings, A (2013), "India's First Elevated, Triangulated Gallery Overland Conveyor", *Bulk Solids Handling*, **33**(6)
3. Suspension Bridge Across Columbia River, Digital Archives ,*Washington State University Library*
4. Similkameen Ore Conveyor Bridge, http://www.highestbridges.com
5. *http://www.doppelmayr.com/en/products/ropecon/*
6. London Millennium Bridge, Wikipedia, http://en.wikipedia.org/wiki/Millennium_Bridge,_London
7. Billah, K.; R. Scanlan (1991). "Resonance, Tacoma Narrows Bridge Failure, and Undergraduate Physics Textbooks", *American Journal of Physics* 59 (2), pp118–124.
8. Huang, Shaojin and Liu, Moshen (2004), "Modern Suspension Bridge", *China Communications Press*, ISBN7-114-05280-4
9. Liu, Dunmin; Liu, Zimin, (2004), "Jiangjun River Suspension Bridge: Test and Calculation", *World Bridges*, 2004, Issue 2 pp56.
10. Yi,Jinpin (2004), "Wu River Penshui Suspension Bridge Design", *Yangtz River*, Vol 35, Issue 12
11. Zhang,Shaobin; Yang,Shenjun, " Study of Design and Construction of Steel Suspension Bridge", *Guizhou Water Power*, 2008, Vol22 Issue 2
12. Arroyo Cangrejillo Pipeline Bridge, *http://www.opacengineers.com/projects/Cangrejillo*
13. Steven, R. (2008), "Belting the World's Longest Single Flight Conveyor", *Bulk Solids Handling*, **28**(3).
14. Vlkram, K, Mukhopadhyay P. (2008), "Limestone Transportation by 17-km Cross-Border Long Belt Conveyor for Lafarge Surma Cement Limited.", in *Bulk Material Handling by Conveyor Belt 7*, Publisher Society for Mining Metallurgy & Exploration.