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Rope Equalizer Systems for Towerless Vertical Lifts

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Introduction

The majority of vertical lift bridge lift spans essentially hang from tall towers. However, there are several lift bridges that do not have towers. These towerless vertical lifts, also referred to as table bridges, have legs that extend below the span. Counterweight ropes, attached to the bottom of these legs, lift the bridge from below – opposed to the more common vertical lifts which are pulled from above. When anything is supported significantly below its center of gravity, it is considered top heavy and is more susceptible to external forces and uneven driving forces. Equalizer systems are used to ensure that the span remains level during lifts. One such equalizer system that is installed on several of the City of Milwaukee's towerless vertical lift bridges utilizes wire ropes, sheaves, and drums that link the span to the piers to stabilize the span. The purpose of this paper is to show how these rope equalizer systems operate on this less common type of lift bridge.

Vertical Lift Basics

Most vertical lift bridges consist of a lift span and counterweights connected via several counterweight ropes which travel over counterweight sheaves. Typically the counterweight sheaves are located at the top of towers near each end of the lift span. Different drive systems can be and are used to raise and lower the lift span. Span drive and tower drive systems are the most popular drive systems for vertical lift bridges with towers. The differences between these two types of systems, their merits and downfalls are a topic for another time. Regardless of the type of drive system installed on the lift bridge, the counterweights and the counterweight ropes do the majority of the lifting work. The counterweight rope span attachments are essentially the supports of a raised span.

Towerless Vertical Lift

Though towerless vertical lifts, as their name suggests, do not have towers, there must be ample space below the span to fit the counterweights and also lifting legs which extend below the deck of the lift span. A common way to accomplish this and still get a reasonable lift height is to form pits within the piers. Counterweight sheaves are positioned below the deck of the lift span, mounted to the pier. One end of each counterweight rope is attached to a counterweight and the other end is attached to a lifting leg. When the span lifts, the counterweights descend into the pier pit as the lift legs, and the span to which they are attached, raise.

Of course, there must be a drive system which raises and lowers the bridge. The common drive system for these bridges is to use hydraulic cylinders to raise the span and allow the span to lower by gravity. Typically there are one or two cylinders in each pier. Though the robustness of hydraulic equipment has improved, there could be a pressure or flow differential between the drive cylinders. This could cause the cylinders to extend and retract at varying velocities, which would lead to an unlevel span. Differences in frictional forces at the corners of the lift span and between the lifting cylinders can also cause them to move at different speeds unless the flow to each cylinder is equalized, internally or externally. The lift heights for these towerless vertical lifts are relatively short, with a maximum lift of approximately 15 feet. Therefore, when the span is fully raised, the extended length of the hydraulic cylinders is in excess of 30 feet. Due to the gravity lower aspect of the span, typically the bridge is significantly span heavy.

Response to External Forces

When a lift span is seated, it is relatively stable as it rests on its bearing points. However, when the span is raised and it is suspended by the counterweight ropes, external forces such as wind may cause the raised span to translate and/or rotate. Uneven frictional forces on the span could also lead to span rotation. Hopefully when the span moves, it remains level, or at least level enough that it does not uncontrollably tip. Span guides are typically installed on vertical lifts to prevent significant translation of the entire span. Though, reactions from span guides could lead to span rotation. Resistance to rotation is a function of the span stability. The stability of a raised span that is supported by ropes is dependent on the location of the counterweight rope attachments relative to the center of gravity of the span and the location of the external force(s). Any stationary object that is supported from above its center of gravity is considered to be in stable equilibrium. An external force may move it, but it will return to its original stable position. If an object is supported from below, it is considered to be in stable equilibrium if its center of gravity is above its base support. If the center of gravity is directly above an edge of the object's base support, then the object would very easily tip if under the influence of an external force. To visualize this basic concept, think of a person standing who gradually leans over. As soon as the person's center of gravity is no longer directly above the area outlined by his feet, he will fall. In the case of a raised lift span, the area of its base support is the area within the points of the counterweight rope attachments. For all lift spans, the center of gravity is well within the span's base support. Therefore all properly balanced vertical lifts should be considered to be stable. However, as the vertical distance between the base support and the center of gravity increases, the easier it is for the span to rotate from external forces. In the case of a raised towerless vertical lift, with the counterweight attachments significantly below the span's center of gravity, the span could begin to tip from external forces. It would take very significant external forces for the span to uncontrollably tip, but it is possible for a horizontal wind or uneven frictional forces to cause the span to become unlevel.

Equalizer Systems

Due to the possibility of the span becoming skewed, from uneven driving forces, from an eccentric span load, or from external forces, some mechanism or device or a sophisticated hydraulic system is required to ensure the span remains level during operation. Just like most aspects of the movable bridge industry, there is more than one way to stabilize the lift span of an operating towerless vertical lift. The equalizer system presented here is what is installed on the majority of the City of Milwaukee's towerless vertical lifts. A system of wire ropes, sheaves and drums link the lift span to the piers providing stabilization during operation. There are typically four independent equalizer systems per bridge: two transverse equalizer systems which are located in the piers, and two longitudinal equalizers which are located along the length of the span with the ropes terminating in the piers. The rope ends of the transverse equalizers are attached to the lift span and the sheaves and drum over which the ropes travel are mounted to the pier. Conversely, the longitudinal equalizer rope ends are attached to the piers and the sheaves and drum are mounted to the lift span. The basic concept is that if the lift span would begin to tip, certain rope segments will go into tension while others go slack; thus preventing the span from tipping further.

Transverse Equalizer System

Two wire ropes are used per transverse equalizer system. One end of each rope is attached to the span just below the deck with the other end attached near the bottom of a lift leg. The ropes are wound around a grooved drum near centerline of the span and travel over deflector sheaves such that the ropes are approximately vertical at the rope end connections. See Figure 1 for a view of a transverse equalizer located within one pier. Figure 2 shows a view of the bridge in the lowered position and in the raised position.

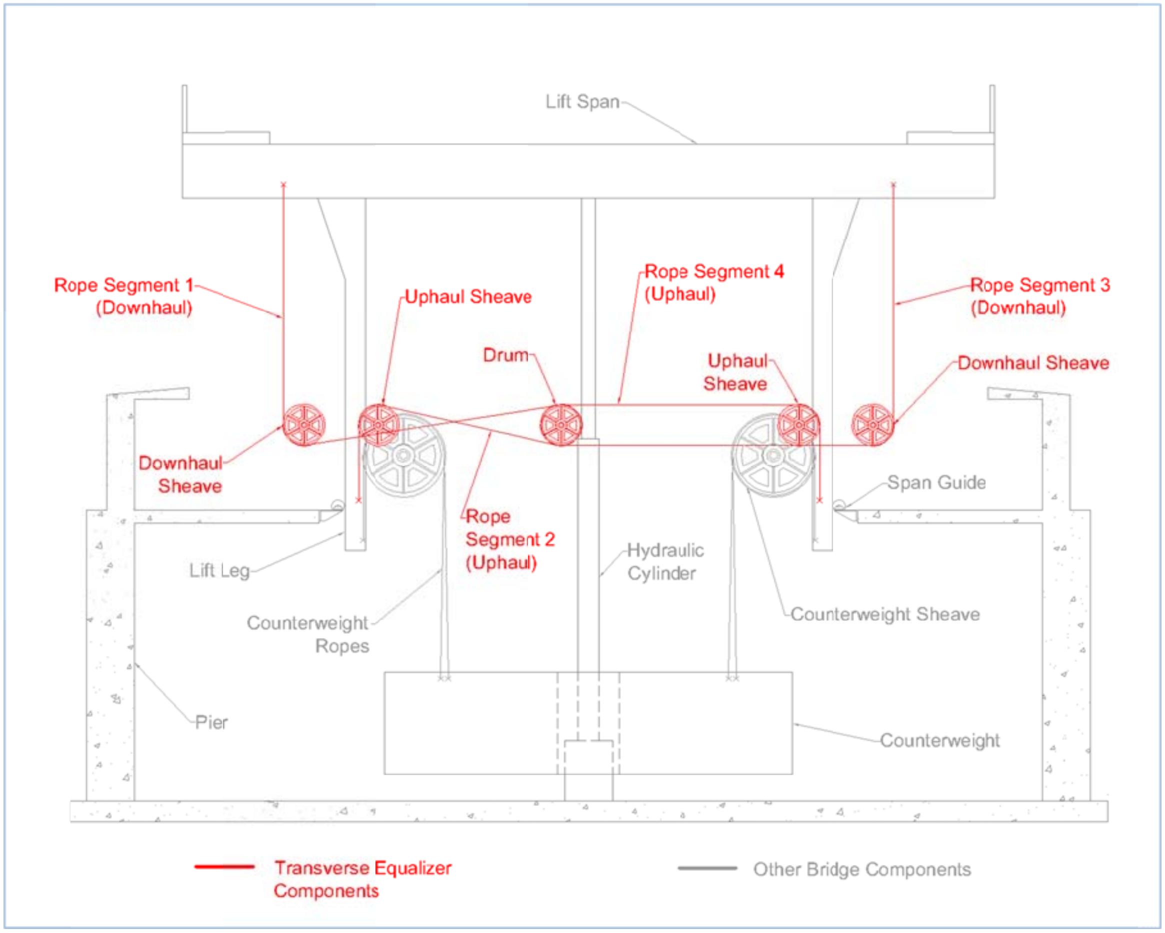

Figure 1 - Elevation End View of Raised Lift Span. Longitudinal Equalizer not Shown

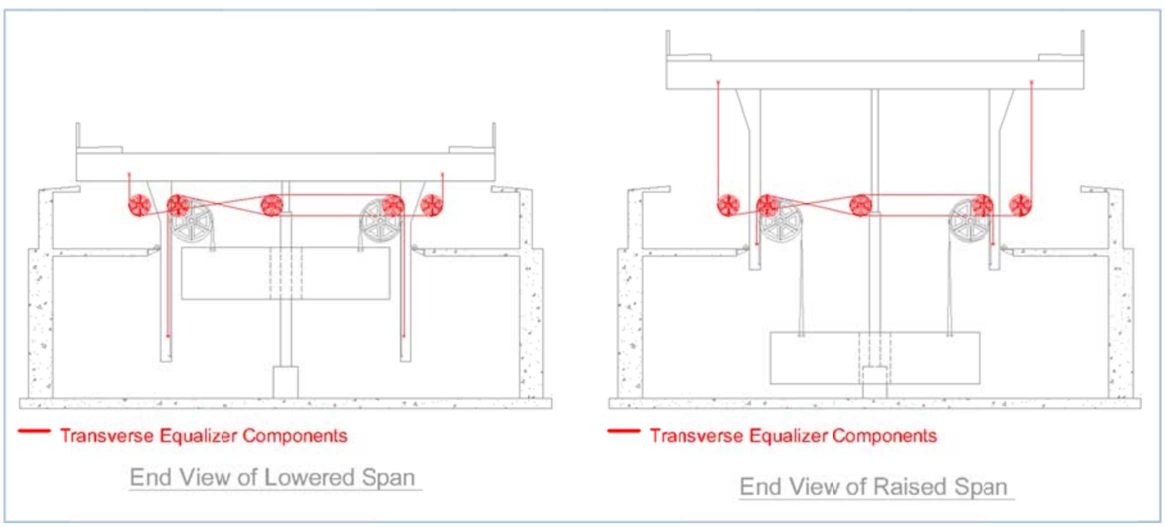

Figure 2 - End View of Bridge in Lowered and Raised Positions

Similar to operating ropes used on span drive tower-type vertical lift bridges, the equalizer ropes can be thought of as having uphaul segments and downhaul segments. However, unlike operating ropes, the drum is not driven by the operating machinery. Rather the ropes turn the drum. The downhaul segments turn the drum when the span is raising and the uphaul segments turn the drum when the span lowers.

Rope segments 1 and 2 are one continuous rope that is attached to the drum with a U-bolt, or something similar. Likewise, rope segments 3 and 4 are one continuous rope attached similarly. As the lift span operates, the drum and sheaves remain in the same location since they are mounted to the pier. If the span is properly balanced and operating in calm conditions with properly functioning hydraulic cylinders, then the equalizer ropes essentially go along for the ride with only slight tension. However, if the span starts to tip, then one uphaul segment and the downhaul segment on the opposite corner will develop tension. Thus providing the forces required to keep the span level. Consider the case where a combination of an eccentric span load and a transverse wind load cause the span shown in Figure 1 to begin to rotate clockwise. Tension would be developed in rope segments 1 and 4 while segments 2 and 3 would go slack. The tension that must be developed in the equalizer ropes to stabilize the span can be estimated via equations of equilibrium. It should be noted that the hydraulic cylinders that drive the span typically have only a friction connection with the lift span. Therefore there cannot be a moment reaction, and only a relatively small horizontal reaction at this connection. If the cylinder were rigidly attached, or even pin connected, it would contribute to the stabilization of the span, depending on the stiffness of the extended cylinder. With the reasonable assumption that the extended cylinders are flexible enough that there would be a negligible horizontal or moment reaction at the cylinder connections, then the calculation is simplified. Consider the diagram shown in Figure 3 representing a simplified free body diagram of a raised lift span under the influence of a transverse wind. With knowledge about the geometry of the span and location of equalizer ropes and assumptions about loading, the required tension to prevent rotation can be calculated.

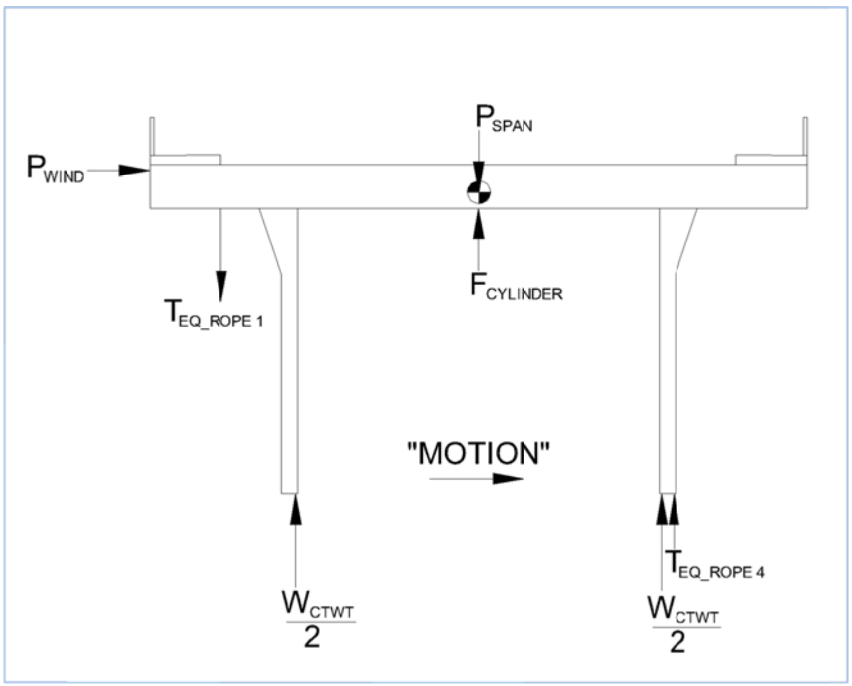

Figure 3 - Free Body Diagram of Raised Span

With one of these systems in each pier, together they provide the bracing required to prevent the span from tipping in the bridge transverse direction. Note that this system will not prevent the span from translating if under the influence of a horizontal external force. However, just like vertical lifts with towers, towerless vertical lifts have span guides preventing translation of the entire span. The typical span guides used in conjunction with these equalizer systems consist of rails mounted to the lift legs, which interface with a roller mounted to the pier. Once the span contacts the span guide, it provides a reaction to counter the horizontal wind load. See Figure 4 for the free body diagram of the span after it has contacted the span guide.

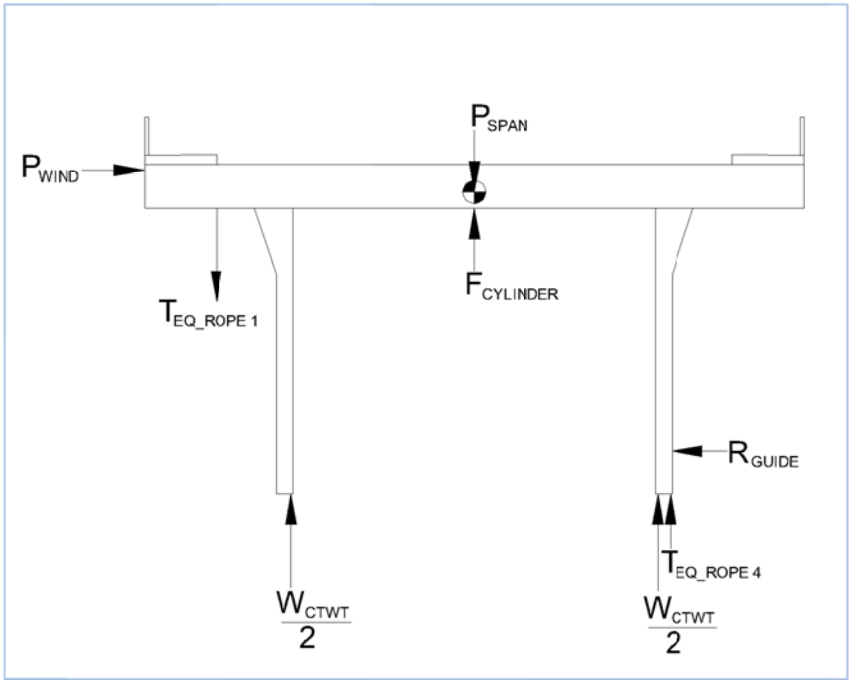

Figure 4 - Free Body Diagram of Raised Span After Contact with Span Guide

Note that if there is not a significant horizontal reaction at the cylinder, the tension developed in the equalizer ropes is essential to keeping the span level.

Span Without Transverse Rope Equalizer

The preceding explanation and diagrams indicate only one hydraulic cylinder providing the driving force per pier. There are, however, towerless vertical lifts that have two cylinders in each pier. Two cylinders per pier will clearly make the raised span more stable and easier to control via hydraulics. Sophistication can be added to the hydraulic system to eliminate the potential of uneven driving forces and to counter the effects of uneven friction. However, the span is still susceptible to external forces such as wind. Consider a bridge without the rope equalizer as described above, but with two cylinders per pier, under the influence of a horizontal wind load. The span would translate, and possibly slightly rotate, until it contacts the span guide. The distance the span has to travel before contacting the span guide is on the order of ⅛ to ½ inch, depending on temperature, installation and other tolerances. Consider the typical span guide as described above with essentially one location of point contact per lift leg, all at the same elevation. After span guide contact, we have a similar situation as shown in Figure 4, but without the reactions from the rope equalizers. The span guide reaction would counter the horizontal wind load, but, depending on span imbalance, an additional reaction or reactions would be needed to prevent rotation of the span. If the hydraulic cylinders cannot provide this required reaction, the span would rotate until the other lift legs contact the span guides on the opposite side of the span. See Figure 5.

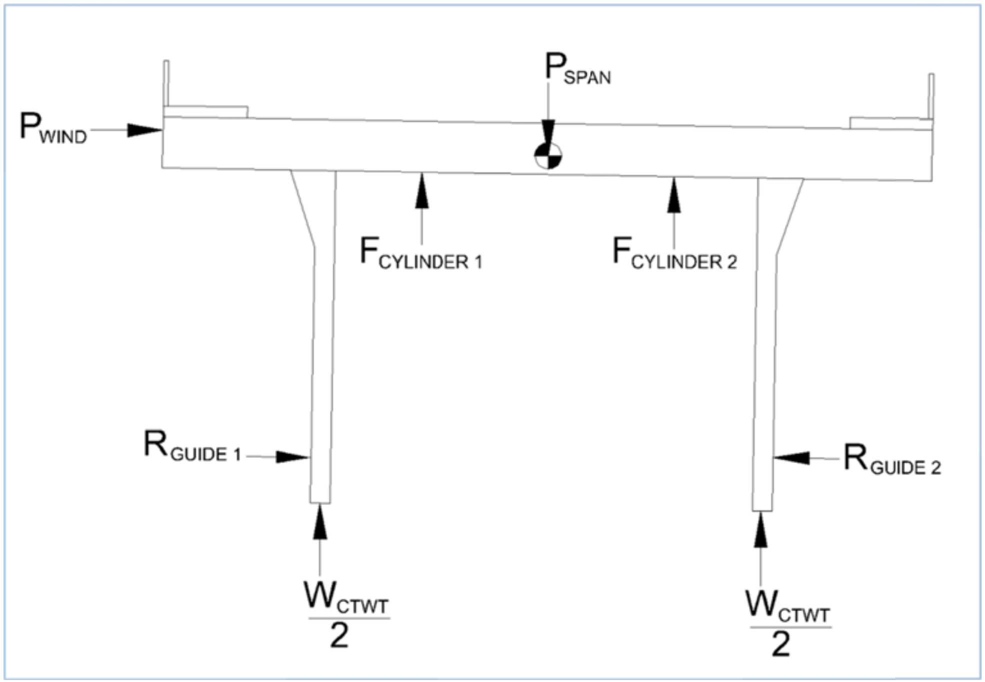

Figure 5 - Diagram of Span under Influence of Wind, Contacting Multiple Span Guides

The amount of rotation that would occur is again dependent on the gap between span guide and lift leg. The span would likely rotate at most 2-3 degrees before all lift legs are in contact with their respective span guide rollers. Due to the large distance between the wind load and the span guide rollers, and the small distance between the roller reaction lines of action, the roller reactions could be fairly large, depending on the amount imbalance between the span and counterweight. These span guide reaction forces will have to be resisted by both the span guides and the lift legs which are relatively long singly supported members. Deformation and/or binding could occur. This scenario does assume single point contact span guides at same elevations and that the hydraulic cylinders do not appreciably assist countering the torque induced by the wind load and guide reaction. Likely, a well-designed span guide system, and / or a sufficiently span heavy condition would be sufficient to prevent the span from binding. However, rope equalizers, installed properly, are always there ready to resist this torque on the span that is created by a wind load and its subsequent span guide reaction. Rope equalizers provide a secure reliable stabilizing mechanism that has been installed on several towerless vertical lifts for over 40 years.

Longitudinal Equalizer System

Similarly to the transverse equalizer systems, each longitudinal equalizer system uses two wire ropes wound around sheaves and a drum. However, unlike the transverse equalizer ropes, the longitudinal equalizer ropes have their ends fixed to the piers while the drum and sheaves are mounted to the lift span. Instead of the rope end terminations directly reacting with the span, the longitudinal equalizer system influences the span via the sheave and drum shaft bearing reactions, which are of course dependent on the tension in the ropes. See Figure 6 for a labeled view of a longitudinal equalizer system with the lift span raised, and Figure 7 for a view of a longitudinal equalizer system on a side view of the bridge in the lowered and raised positions.

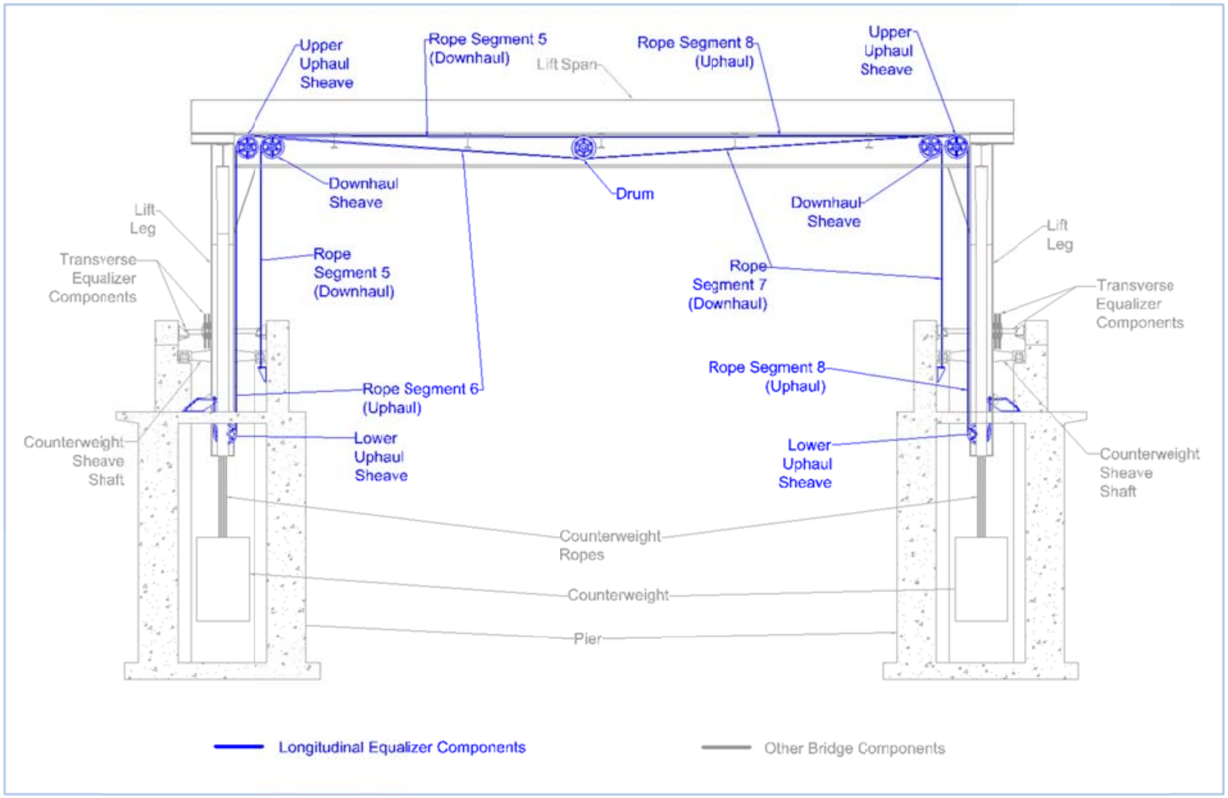

Figure 6 - Elevation Side View of Bridge with Raised Lift Span. Hydraulic Cylinders not Shown.

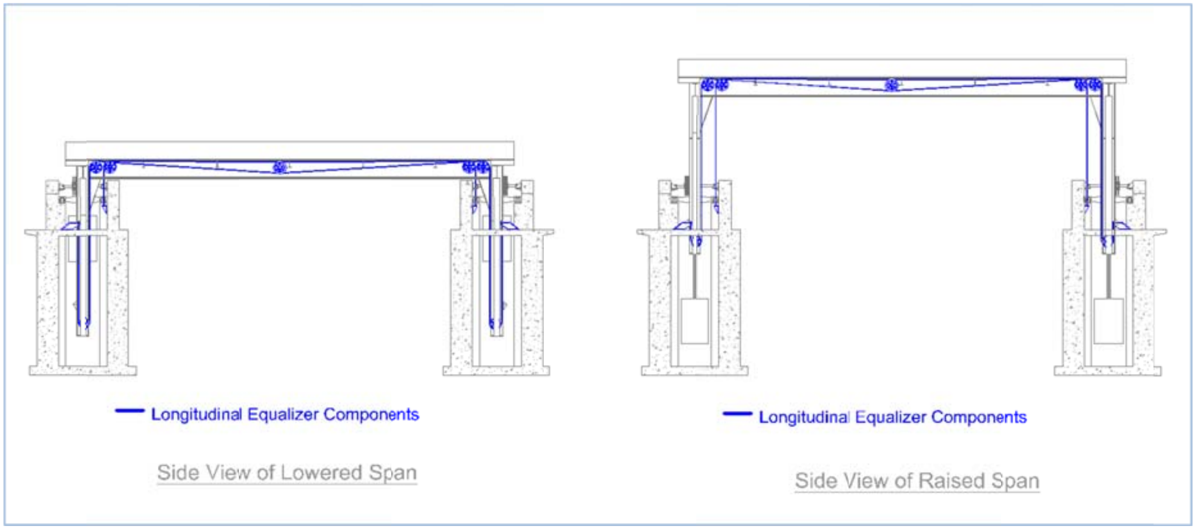

Figure 7 - Side View of Bridge in Raised and Lowered Positions

Typically, there are two of these systems per span, positioned longitudinally along the span, in line with the lift legs. They function very similarly to transverse equalizers in that an uphaul rope segment and the opposite downhaul rope segment become tensioned, essentially putting a couple on the raised span, if the span begins to become unlevel.

The longitudinal equalizers can transfer some of the driving force from the cylinder(s) in one pier to the lifting legs in the opposite pier such that lifting forces are equalized allowing the span to raise evenly. If one cylinder is sized adequately to lift the entire span, the rope equalizers could distribute the driving force sufficiently to raise the span. For the case where there is only one cylinder per pier, this would require a somewhat oversized hydraulic cylinder and large equalizer components. However, reasonably sized equipment can be used to accomplish this for the case with two cylinders per pier. Consider one of the four cylinders completely removed. Essentially the cylinder force from one pier would be half that of the other pier. For this case there would also be uneven cylinder forces from one side of the span to the other, but we have transverse equalizers to accommodate for this. If the bridge shown in Figure 6 has raising forces higher in the "left" pier than the "right" pier, either from higher frictional resistance in the "right" pier, or more cylinder force in the "left" pier, then rope segments 5 and 8 would develop tension while segments 6 and 7 would go slack. Note that the uphaul rope segments travel around two deflector sheaves: an upper uphaul sheave and a lower uphaul sheave. Though the upper uphaul sheave actually provides a downward force on the span, the net force on the span from the upper and lower uphaul sheaves is in the upward direction. Similar to transverse equalizer ropes, longitudinal equalizer rope segments 5 and 6 are actually one continuous rope and segments 7 and 8 are one continuous rope.

Adhering to current AASHTO Specifications, the equalizer systems and hydraulic cylinders can be designed to lift the span using three of four hydraulic cylinders. This redundancy is a significant added benefit that rope equalizers provide. If repairs must be made to a cylinder, the bridge can remain operable.

Conclusion

The configuration of towerless vertical lift bridges, with the counterweight ropes attached significantly below their center of gravity, makes them susceptible to span rotation. An eccentric vertical load, a horizontal load, uneven driving forces, or uneven friction all can induce unwanted rotation of the span. A mechanism that has proven in the field to provide adequate stabilization for these spans utilizes wire ropes and sheaves to link the raised span to the piers. Though rope equalizers do add a fair number of components and some maintenance, the added stability is important on towerless vertical lifts.

While a four cylinder configuration with a sophisticated hydraulic system could eliminate the need for a rope equalizer system, it is important to have a well-designed strong span guide system and / or a significant span heavy condition. A less sophisticated hydraulic system with rope equalizers provides adequate redundancy for the instability potential, and span guides need only resist translation of the span.

An additional benefit of rope equalizers is that repairs can be made to the hydraulic cylinders without taking the bridge out of commission. Rope equalizers can be designed such that the span can still be lifted when one or more hydraulic drive cylinders are removed.

Though rope equalizer systems have been referred to as Rube Goldbergish, they are actually simple robust mechanisms that provide an important function on towerless vertical lift bridges.