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Counterweight Wire Rope Replacement: Evaluating Wire Ropes for Replacement and Considerations in Performing Rope Replacement Work

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Introduction

Counterweight wire ropes are a crucial component of vertical lift bridge machinery that are expected to provide a long service and must be monitored and replaced when necessary. This paper presents the common methods of evaluating counterweight ropes for replacement and the considerations in performing rope replacement work. The paper discusses considerations in planning rope replacement work to address the challenges such as site constraints and limited marine, vehicular traffic, and/or rail outages. Different rope installation methods are presented along with common issues often encountered during rope replacement projects, and lessons learned.

Evaluation for Replacement

Wire Ropes

Counterweight ropes that are appropriately designed, well maintained, and not subjected to adverse conditions can be expected to last in excess of 50 years. The three main causes of rope issues are fatigue, abrasive wear, and abuse. The AASHTO Movable Bridge Inspection, Evaluation and Maintenance Manual provides steps for inspecting counterweight ropes:

- *Observe the rope during a full operational cycle. Note if the rope contacts any portion of the bridge structure during the cycle. Prioritize inspection of the portion of the rope that is tangent at the tangent point on the counterweight sheave and the end of the rope at the lifting girder area when the movable span is closed, since these are the highest-wear areas of the rope.*
- *Closely examine individual wires for cracks or breakage. List the number of broken wires in one rope lay for each strand. The number of broken wires is a significant factor in determining the remaining life of the rope.*
- *Look for flat areas on the rope. These are areas indicating abrasive wear. Also note the length along the wire of the flattened portion of the wire, as it is a significant factor in determining the remaining life (based on industry standard guidelines) of the rope. The criteria for determining the remaining life of a wire rope can be obtained from the wire rope manufacturers.*
- *Measure the diameter of the rope. Reduction of the diameter is an indication of a problem within the interior of the rope.*
- *Check for dirt and foreign matter in the lubricant and note the adequacy of the lubrication.*
- *Check the sheaves to be sure the rope is properly seated in the sheave grooves.*
- *Observe the wire rope for any distortion such as kinking, crushing, main strand displacement or core protrusion.*
- *Check for corroded or broken wires at end connections.*
- *Measure and record the tension in all wire ropes.*
- *Tension values should to be compared with original and previous report values.*

There is not a standard specific to the replacement of movable bridge counterweight ropes. The most applicable standard with quantitative criteria is for Underground Mining Hoist from the Code of Federal Regulations section 30 CFR § 77.1434 Wire Rope Retirement criteria:

Unless damage or deterioration is removed by cutoff, wire ropes shall be removed from service when any of the following conditions occurs:

- *(a) The number of broken wires within a rope lay length, excluding filler wires, exceeds either—*
  - *(1) Five percent of the total number of wires; or*
  - *(2) Fifteen percent of the total number of wires within any strand;*
- *(b) On a regular lay rope, more than one broken wire in the valley between strands in one rope lay length;*
- *(c) A loss of more than one-third of the original diameter of the outer wires;*
- *(d) Rope deterioration from corrosion;*
- *(e) Distortion of the rope structure;*
- *(f) Heat damage from any source;*
- *(g) Diameter reduction due to wear that exceeds six percent of the baseline diameter measurement; or*
- (h) *Loss of more than ten percent of rope strength as determined by nondestructive testing.*

Figure 1: Heavy wear on the sides of the ropes that has progressed through the outer layer of wires. The ropes were only in service for approximately 10 years.

In addition to wear flats that predictably develop where ropes contact the sheave grooves, there have been instances where wind induces ropes slapping/rubbing against each other or parts of the structure. This wear tends to progress much faster than from the ropes against the sheave.

Take-ups and Other Hardware

Counterweight rope replacement projects are almost always initiated based on the condition of the wire rope; however, the associated components like pins and take-ups must also be evaluated to determine if their replacement is necessary. Where counterweight ropes are terminated with open spelter sockets the pins should always be planned for replacement for two main reasons. First, this ensures the sockets and pins can be manufactured to provide an appropriate fit-up between them. Second, there is significant risk of the existing pins being seized in their existing sockets requiring destructive removal.

The cost of replacing rope take-ups can be significant and the condition of take-ups often appears to be good in the easily visible portions of existing installations. Often, however, the portions that are not easily visible are at the highest risk for being in poor condition. One of these locations is the portion of the take-up that passes through the lifting girder/billet. Another location is at the thread stick which is often obscured by a cap nut. Cap nuts are often provided with drain holes at the bottom, but these can become sealed by debris or paint leading to moisture being trapped within the cap. Beyond corroded threads, take-up nuts that have become seized and require hydraulic torque wrenches to remove the nuts can result in damage when breaking the nut loose.

Figure 2: Heavily corroded threads were discovered in the portion of the take-up that passed through the billet.

Figure 3: A take-up nut was seized and the threads were damaged when using a hydraulic torque wrench to remove the nut.

The schedule of work and outages can also be a factor in the decision to re-use or replace rope take-ups. In situations where the marine outage can be significantly long, such as where a waterway freezes for the winter or boat traffic is seasonally limited, the work plan can include time for blast cleaning, repairing threads, and painting. Where the marine outage time is very limited, it may be necessary to plan for replacing take-ups to avoid the time associated with rehabilitating existing take-ups. In addition, removing existing take-ups using means and methods required to prevent damage can require significantly more time than destructive removal.

The lead time to fabricate take-ups can be significant. It is critical for owners to consider the risks of finding take-ups that are unsuitable for re-use and implement contingency options when choosing to re-use existing take-ups.

Jacking Lift Span and Counterweight

Many vertical lift bridges are provided with a counterweight hanger system which can be used for unloading the counterweight ropes. Some of the hanger systems are designed to jack and lift the counterweight while others support the counterweight in a single fixed location. In fixed hanger arrangements, the span must be jacked to unload the ropes. If the lift span must be jacked, the span must be closed to vehicular traffic while jacked. Some bridges are designed with designated jacking points on end floorbeams, while others may require engineering evaluation and added strengthening to resist the jacking loads.

Rope manufacturers and the Wire Rope Users Manual provide estimates for the constructional and elastic stretch based on the rope construction. These are used to determine the expected amount of jacking. It is not uncommon to experience greater than the expected constructional and elastic stretch and it is strongly recommended to provide additional range of jacking to account for this. The additional range of jacking should be in both the raising and lowering directions to ensure terminations can be made as well as loading the ropes prior to jacks bottoming out.

Jacking lift spans or counterweights often require large capacity hydraulic cylinders which may not be readily available in double acting configurations. When the total jacking distance is greater than the stroke of the cylinder, resetting the cylinder is part of the jacking process. Depressing the cylinder can require significant force even with the pump line set to retract. To account for this, a secondary smaller jack or local hydraulic dump line should be included in the jacking system.

Figure 4: Jacking assembly located under lift span end floorbeam. The assembly included an added local dump line (clear tubing) to facilitate retracting the cylinders.

Figure 5: Counterweight jacking assembly located at the top of a tower.

Counterweight Rope Replacement Work

Existing Rope Removal

Removal of existing counterweight ropes is often performed using the same methods that will be used for the installation of the new ropes with a few differences. The ropes being removed do not need to be handled with the care of new ropes, specifically a minimum bend radius and protection from kinks do not need to be maintained. Additionally, clamps or other equipment that could crush the rope can be used.

Removing take-ups and pins can be a difficult process where components are seized. Contractors often choose to cut the wire ropes near the sockets to simplify the removal and handling of the ropes. Take-ups and pins can then be removed separately.

As noted above, removal of take-up nuts can be difficult and at times impossible without destructive methods. If the work plan includes re-use of take-ups, time in the outage schedule must account for the challenges in the removal process. In addition, a minimum number of spare components should be provided to account for components that are not suitable for reuse due to found damage or destructive disassembly.

Socket pins are often seized to the socket or mating connection. The work plan should include means of disassembly of pins. A common counterweight connection arrangement includes a set of counterweight end sockets terminating on opposing sides of a splay casting plate. This limits access to only one end of the socket pins. To remove seized pins, a successfully used option is to weld a nut to the end of the pin and then, with a threaded rod, jacking stool, and center hole cylinder, jack the pin out. During time constrained outages, the nuts can be welded in advance of the outage and be ready for use.

Figure 6: The counterweight end pins are seized and nuts are welded on to remove the pins with jacks.

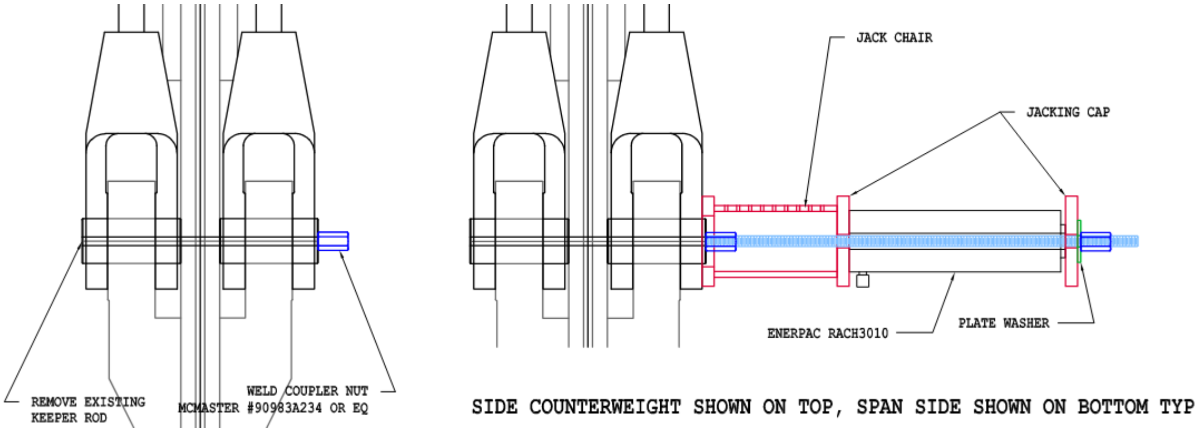

Figure 7: Counterweight pin jacking assembly.

Methods of Installation

There are various methods for installing counterweight ropes up and over their counterweight sheaves. These methods include lifting with a crane, winches, or even a helicopter. The preferred method is typically governed based on site access, whether the counterweight sheaves are in an enclosed machinery room, length of marine outages or traffic closures, and cost.

Crane

While the use of a crane can be generally straightforward in terms of lifting and placing ropes, it is the most constrained by site access. The type and capacity of crane that can be used is governed by the weight of the rope assembly, height of the tower, and the crane location relative to the tower. In situations with smaller diameter ropes and lighter overall weights, truck mounted cranes have been used that can drive up to the bridge and be positioned on the approach to a tower. Where larger capacity cranes are needed, there needs to be sufficiently large and stable land adjacent to the bridge as well as clearance from other structures to swing booms as needed. Barge mounted cranes are an option but come with increased cost and complications of working over water.

Figure 8: Counterweight rope installation with a crane and spreader beam.

Besides land or barge access for the crane to be located, using a crane also requires overhead access to the counterweight sheaves. Counterweight sheaves must either be at the top of an open tower or the machinery room/sheave enclosure must be at least partially disassembled to permit overhead access.

Winch

The use of winches for installing ropes avoids many of the site constraints of using a crane, such as needing overhead access to the sheaves or needing significant space to locate the crane. The use of a winch can provide flexibility as well as complications. There is flexibility in where the winch can be located, whether at the top of the tower, at roadway level, or on top of the counterweight. Additionally, multiple winches can be used simultaneously (one per sheave) which is not feasible with a crane. A winch also avoids some of the potential restrictions with swinging a crane over live traffic or active rail lines. Offsetting the flexibility are the complications. These complications include installation of deflectors to pass through

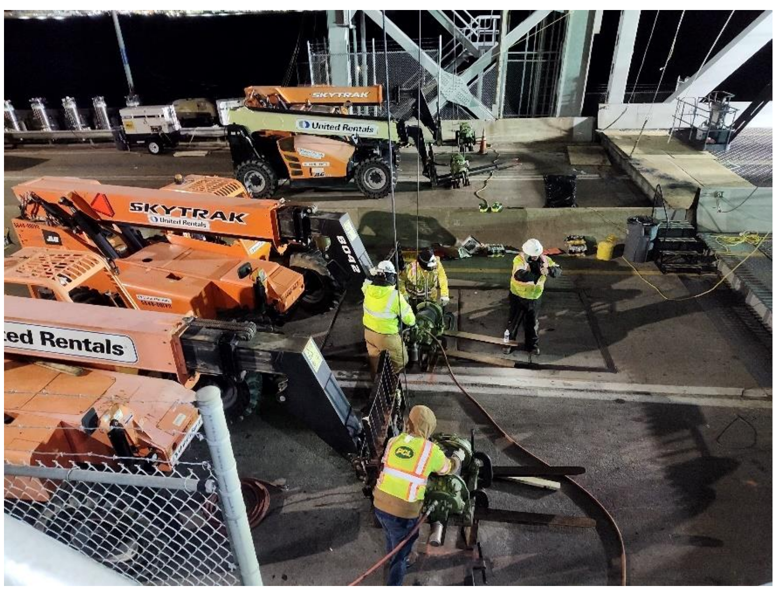

Figure 9: Four winches mounted to forklifts at the roadway level, one per counterweight sheave.

openings and avoid the structure, snatch blocks orient the direction of pull, and the need for re-rigging or changing attachment points during the installation.

Figure 10: Counterweight rope installation with a helicopter.

Helicopter

Beyond the most common methods, outside the box options such as the use of a helicopter have been used. The use of a helicopter is similar to a crane in terms of overhead access. A helicopter can be used when the site conditions do not make placement of a crane adjacent to the bridge feasible. A helicopter also provides flexibility in locating a staging area that may be farther from the bridge.

Handling

Counterweight ropes are generally shipped to the bridge site on reels and it is often not practical to pull the rope directly off the shipping reel to install it. More commonly the ropes are pulled off the reels and laid out on plywood sheeting in a staging area. The plywood provides protection from dirt and other contamination and it provides a surface the ropes can slide on without causing damage. Once ropes are laid out, connection points for rigging can be accurately measured from rope ends. Additionally, on bridges where multiple different rope lengths are used, this mitigates the risk of installing ropes at incorrect locations. But ropes can be pulled directly off shipping reels if it is preferred or if there is insufficient staging space. In these situations, it is important to procure or fabricate reel stands that incorporate a brake to control rotation of the reel. The reels can develop significant rotational momentum as a rope is being pulled off. Also, the location of sockets on the reel will lead to the tendency for it to rotate until the heavy point of the reel is at the bottom.

Figure 11: Counterweight ropes pulled off the shipping reel in preparation for installation with a winch.

Due to the tight fit between rope sockets and their pins and their often relatively large size, it is much easier and preferable to assemble take-ups with the ropes while in the staging area rather than attempting to assemble the rope with take-ups installed in lifting girder or counterweight terminations. This requires additional effort in protecting the take-up threads during the installation process, but this effort has been relatively minor.

When handling the counterweight ropes it is important to prevent kinks and avoid a sharp bend radius which can cause permanent damage to the ropes. Ropes must also be installed without twist. A paint stripe is typically painted along the rope during fabrication and it must be confirmed to be straight when connecting the rope end terminations.

Figure 12: Counterweight ropes pulled off the shipping reel in preparation for installation with a crane.

Although it is difficult to directly quantify, our experience indicates an apparent correlation between the amount of handling of a rope and the amount of constructional stretch. As a result, it is desirable to minimize the amount of handing in an effort to reduce the construction stretch break in process and the corresponding variation in tension from initial loading.

Project requirements have varied substantially in terms of protection requirements of ropes, sockets, and sheaves during the installation process. The most restrictive being that ropes are not permitted to slide in the sheave grooves at all, even when unloaded, and the least restrictive permitting winch lines and counterweight ropes to directly ride in the sheave grooves, even while loaded with the full weight of a rope assembly. In our experience, no wear or damage to the sheaves or ropes has been observed from ropes sliding in the grooves during both the removal and installation process. Therefore, the added means to prevent sliding in the sheave groove, which can be complex, do not provide a measurable benefit to the project.

Rope Tensioning

One of the final steps in a counterweight rope replacement project is tensioning of the ropes.

Sequence of Tensioning Work

Once counterweight ropes are installed and the terminations at both ends are made, the following is the general process for tensioning:

1. De-jack the span/counterweight while observing the ropes for any significant differences in tension (one or a few ropes becoming visibly taught while others are visibly slacked). Stop the de-jacking process to adjust take-up nuts/turnbuckles/socket shims as necessary.
2. Perform initial tension measurements with all ropes fully loaded. Adjust the tension of any ropes with tension greater than 25% more than the corner average tension.
3. Operate the bridge through multiple full lifts to exercise the ropes and equalize the tension on either side of the sheaves.

4. Perform rope tension measurements and determine adjustments to bring all ropes within ±5% of the rope group average.
5. Operate the bridge through multiple full lifts.
6. Perform rope tension measurements.
7. Repeat the adjustment, operation, and tension measurement process until all ropes are within ±5% of the rope group average.

Operating the bridge through more lifts, particularly after the initial installation, helps to reduce the number of iterations in the rope tensioning process. This is believed to be related to working out the constructional stretch and reducing the variability in the tensions. This also appears to hold true for later tension re-checks that are typically performed 6 months after installation.

There have been counterweight rope replacement projects for vertical lift bridges with requirements that final rope tensioning be performed following final bridge balancing. Our experience is that final balance adjustments do not affect rope tension deviations.

Tension Measurement Methods

There are a few common methods for determining counterweight rope tensions and they are all based on the fundamental frequency method. This method involves manually exciting the counterweight rope into a first order wave and then using various methods to measure the frequency of the oscillation. The rope frequency is proportional to rope tension. The rope frequency can be converted to rope tension if the rope construction and unsupported length are known. Common measurement methods are:

1. Stop Watch
   The rope is watched or felt and manually timed with a stop watch for a set number of oscillations (typically 40).
2. Accelerometer
   An accelerometer mounted to the rope records the oscillations. Through post-processing, the recorded data is analyzed to output a frequency based on the time for a number of oscillations.
3. Commercial Frequency/Tension Measurement Device
   This device has a probe that attaches to the rope and internally processes the oscillations to display the frequency. Rope properties can be input into the device to directly output tension.

All three methods have been demonstrated to provide similar accuracy and repeatability when performed by qualified personnel.

The accelerometer is the only method that allows for a graphical display of the frequency via post processing. This method is the most time consuming and can slow the tensioning process, resulting in added costs to a project.

The commercial frequency/tension measurement device is the fastest of the three methods, but it is limited in the range of frequencies that can be measured and access to the midpoint of a rope is sometimes required to get sufficient amplitude for reliable measurements. Additionally, this device does not save a record of the frequency/tension output.

Summary

Counterweight wire ropes are a crucial component of vertical lift bridge machinery. The condition must be monitored throughout their service life and counterweight ropes replaced as necessary. There are a variety of different approaches to performing a counterweight rope replacement project. Understanding the project constraints related to site access, lengths of marine, vehicular, and/or rail outages, and cost are critical to efficiently and successfully performing the work.