Technical Memorandum

Overhead Conductor Rail

D2 - Subway

Dallas, Texas
December 30, 2019

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Narrative

The GPC6 Project Team has requested a white paper on the topic of Overhead Conductor Rail (OCR) in order to get a better understanding of the system to allow DART to make an informed decision regarding use of OCR during the construction of the D2 Subway project. The intent of the paper is to describe how OCR is comprised, its typical applications, technical information regarding the typical components, how the system works, and advantages/disadvantages of an overhead conductor rail system compared to a typical overhead catenary system.

What is Overhead Conductor Rail?

Overhead Conductor Rail (OCR) is an alternative distribution system to conventional catenary systems in rail transit. Its characteristics make it the most applicable for fixed infrastructure feature, such as tunnels, bridges and maintenance depots, although its lower maintenance costs justify its installation in a wide range of environments. There are many styles of overhead conductor rail available from proven industry manufacturers.

Along with OCR, the system is also commonly referred to as ROCS (rigid overhead contact system), with other alias' including overhead contact rail, overhead rigid rail, overhead tee bar, overhead rigid bar suspension, and overhead contact bar. In all cases, the premise is the same. With OCR, a method of distributing power to a vehicle is made by installing a rigid tension-less mechanical support system that is low-profile and electrically-capable of maintaining the system's rated voltage. Typically, in a conductor rail system, the rail is directly connected with the contact wire, meaning that it can be integrated into an existing overhead contact line system and provide the same distribution of power to the vehicle below.

Conductor rail offers an alternative to catenary to allow for unique installations that cannot be achieved with catenary. For instance, conductor rail is self-supported and does not require a messenger wire to support the contact wire conductor that distributes power to the vehicles. The system height of the catenary (the required separation of the sagging messenger and contact wire) is reduced and the required mechanical clearances are reduced with the use of conductor rail. This may allow a reduction in the diameter of the tunnel. With conductor rail, the along-track tensile loading found in catenary is not necessary and the need for termination structures that are strong enough to handle that loading requirement is removed.

Availability and Usage

Overhead conductor rail is common throughout the world and widely available. Several manufacturers provide the materials, while others provide the materials, design, and installation services and construction support. Notable manufacturers of overhead conductor rail systems include: RailTech-KLK, Furrer+Frey®, AFL Global, Mac Products, and Siemens.

Overhead conductor rail has been used for trolley pole current collection for many years in various forms and arrangements and more recently for pantograph operation in Europe, on the AMTRAK system, and at transit systems in North America. Albert & J. M. Anderson Company conductor bar was successfully used on the Brooklyn Rapid Transit Company and the Boston Elevated Railway Company systems in the early 1900's. Many trolley bus and streetcar networks used Ohio Brass conductor bar in both steel and copper varieties successfully in trough construction. A straight, trolley bus curve segment bar system is in use in Memphis, Tennessee under bridges. The Furrer+Frey® and Siemens style conductor bar with a trolley wire for a running surface is used in North America on AMTRAK draw bridges and maintenance facilities, LA Metro, and TTC in Toronto. Overseas, the system is currently used in Australia, Taiwan, Thailand, South Korea, Hongkong, China, India, Turkey, Italy, Spain, France, Belgium, Germany, Austria, Croatia, Netherlands, Great Britain, Denmark, Sweden, Norway, Russia, Ukraine, Algeria and Switzerland. The widespread use should lend assurance that conductor bar is a viable alternative to contact wire suspension.

Applications

The following section provides locations where conductor rail application provides benefits to the operating agency over contact wire. HNTB has a wealth of experience in the design of overhead conductor rail. Therefore, included with some of the applications listed below are examples of HNTB-designed instances of conductor rail installation that have been successfully installed to the client's satisfaction and continue to provide high quality performance.

Tunnels

One of the most practical and beneficial applications of conductor rail is inside tunnels. The overhead conductor rail system makes it possible to choose smaller tunnel cross-sections for new builds and allows the electrification of existing tunnels originally built for steam or diesel traction. One of this system's major advantages, is its low overall depth, plus the fact that there is no contact wire uplift even if operated with multiple pantographs. The system can be provided with large electrical cross-sections, so that additional feeders can be avoided. Moreover, this system's fire resistance is significantly greater than that of a catenary system.

Possibly the most significant advantage is that this is a tension free installation, which ensures that barring multiple simultaneous failure within the tunnel the live conductors will remain in place. There is no risk of a broken live wire falling within the tunnel. The fact that there is no tension in the contact wire also reduces wire wear, increases longevity of the installation, and simplifies maintenance in what will normally be a difficult location to access.

Furthermore, high performance catenary systems are defined by either completely elastic or completely rigid installations. While not normally required in a tunnel, OCR installations have been proven to perform at speeds up to 145 mph. As such, OCR would normally be the preferred installation everywhere except for the cost of the required frequent structural supports in open route. However, by default the tunnel provides the continuous structural infrastructure at no additional cost.

For all of these reasons, OCR is unmatched as a preferred installation for tunnel electrification.

HNTB recently completed the design for use of OCR in three tunnels for LA Metro.

Other Applications

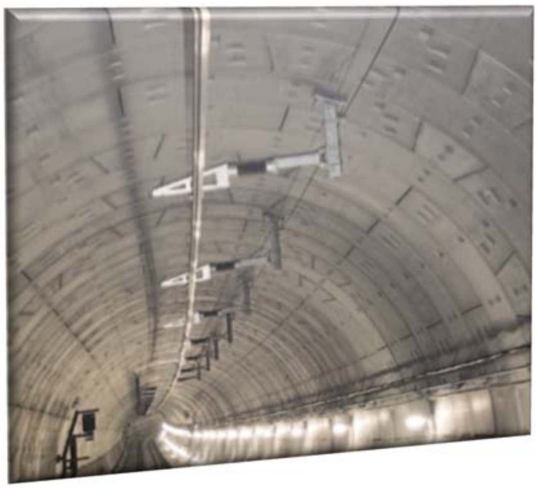
OCR is frequently used in other applications:

- Movable Bridges
- Maintenance Shops
- Under Roadway Bridges

See Appendix A for more information on these applications.

Installation

The typical system installed in the tunnel would include a standard conductor rail bar that is supported from the tunnel ceiling by either a single offset cantilever arm that drops from the tunnel ceiling or by two vertical supports that are relatively centered over the track with a horizontal member between them that supports the conductor rail.



For new tunnels, the supports attachments are typically cast into the tunnel sections. Anchor rods would provide for specific predetermined locations for the conductor rail support, while embedded strut channels could be utilized for location adjustability. For existing tunnels or installations of conductor rail without cast-in place connections, drilling of the tunnel surface would be required to support the system. Mechanical anchors could be installed, with manufacturers providing shallow-depth anchors that are strong enough to support the system. All of the items previously mentioned would be standard off-the-shelf products and have been installed and continue to be in use successfully on many systems today.

Insulators connecting hardware would then be attached to gain the vertical separation required to maintain the electrical clearance to the tunnel itself. The conductor rail supports are typically spaced at 20 feet with spans ranging from 5 to 40 feet. The self-supporting conductor rail would then be attached to the tunnel supports. Conductor rail styles vary, however using a discrete replaceable contact surface is preferred. Many of the recommended manufacturer styles of conductor rail include utilizing a contact wire, which is inserted and clamped into the base of the conductor rail for the pantograph to make contact and run on. This wear-element is easily replaceable and can be provided from the agencies standard contact wire stock.

The attachment of the rail to the tunnel supports is done in a fashion that allows for expansion and contraction of the conductor rail itself. The aluminum bar expands and contracts with temperature change and the system is designed to allow expansion/contraction movement in the length of the bar. To accommodate this action, the bar is anchored in the middle of a tension length and would have expansion joints at specified intervals. Joints must be jumped with cables to prevent arcing and utilize the large cross-sectional area of the bar as a supplementary conductor. Supports would allow the bar to slide through while maintaining stability. In the event of wear of the expansion joint or need for replacement, it can be unbolted without affecting the adjoining section and a new piece bolted into place. Similarly, wear on the contact wire for specific sections can be readily replaced.

The conductor rail can changeover to catenary utilizing transition assemblies that allow a smooth bounce-free transition from tensioned contact wire to the conductor rail. These transition assemblies are constructed from a length of conductor rail that has incremental section pieces removed to provide a one end that is flexible like the catenary and the other end rigid like the next section of conductor rail.

Technical Features

Typical materials and characteristics:

- Rigid catenary solution with an aluminum alloy profile, which provides a lightweight assembly and accommodates the copper contact wire as the running surface.
- Aluminum extrusion with a large cross section for the current which allows operative OCS voltages from 750 to 25,000 V, without any feeding supply.
- Conductor profile manufactured by extrusion from aluminum alloy and heat-treated, in bars of 30 to 40 feet length.
- Self-centering joint plate is designed to deliver ideal alignment between the profiles
- PVC protection cover to protect the aluminum profile against dust and humidity. For use at the entrance of tunnels, high humidity areas, or stations, to improve safety.
- Double insulation can be achieved with the support brackets.
- Maintains stagger of the contact wire for even wear of pantograph carbons.

The following assemblies and components are the major items that comprise the overhead conductor rail system and are largely based on the Furrer+Frey system (which is almost identical to the RailTech-KLK and Siemens systems).

Conductor Rail

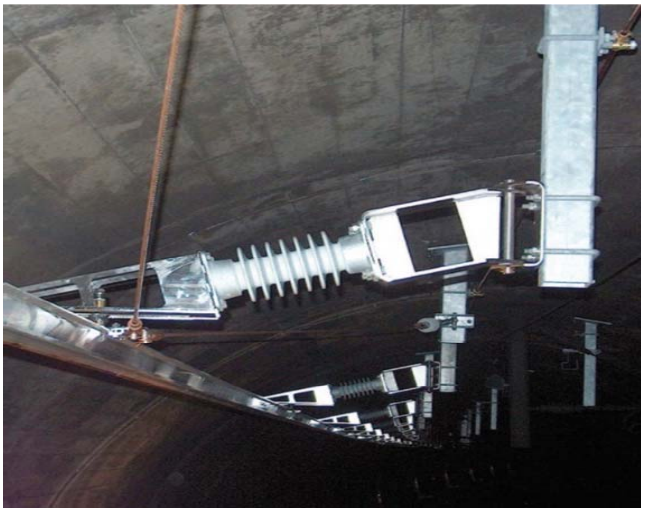
Made of extruded aluminum, the widely used box-shape profile has become more sophisticated as a result of experience gained over the years. An untensioned contact wire is clamped to the lower side of the profile by means of a special insertion device. Contact wires of varying sizes can be accommodated in the base. A special anti-corrosion grease prevents ion exchange, thus permitting the use of copper contact wires with the aluminum body without concern for the dissimilar metals. Because of the rail's large cross section, there is no need for auxiliary lines such as feeders and cables.

Interlocking Joints

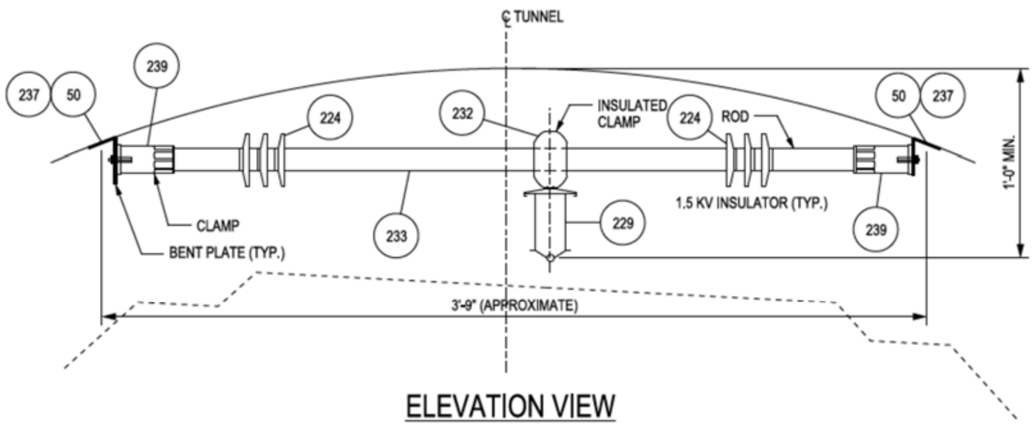
Conductor rail profiles are joined by using pairs of interlocking joints with bolted connections. The groove and rib system between the conductor rail profile and interlocking joint ensures that the joints are formed free of any kink and, at the same time, it ensures optimum current transfer due to the numerous single point and continuous linear contacts between the profile section and the interlocking joints.

Support Structures

The overhead conductor rail replaces the catenary system in particular circumstances and/or because it is more reliable. Presently, there are many types of support structures available from the manufacturers directly, or engineered supports can be designed to support the conductor rail with typical steel members when combined with the manufacturer's components. That is typical, as owners want unique solutions that suit their specific application with



preferred reaches and adjustability that go beyond what the supports may provide.



ELEVATION VIEW

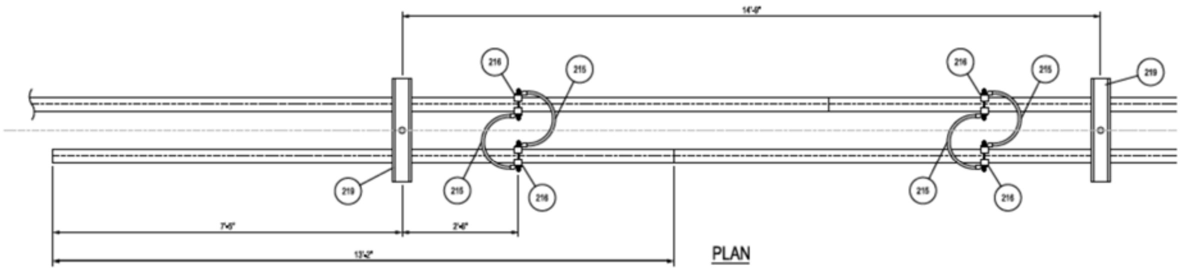
CR-OH-02
CONDUCTOR RAIL
TYPICAL SUPPORT ASSEMBLY
IN TUNNEL

Support Attachment and Adjustability

Adjustment is still provided in the assemblies themselves. The fine adjustment of the height at which the overhead conductor rail system is positioned is obtained by using swivel heads on the support structure. The swivel heads allow for rotation of the conductor rail but also allow for vertical adjustment as well. The swivel heads may also contain spring stacks. Depending on train speeds and where the support structures are situated, the spring stacks are included with the components such as expansion joints or section insulators. The stacks help to achieve the optimum dynamic behavior between overhead conductor rail and pantograph.

Expansion Element

Like in a catenary system, temperature changes also produce changes in the length of the overhead conductor rail. Changes to its length are compensated for by expansion elements cut into the axis of the conductor rail. The expansion joints allow the pantograph to run smoothly without mechanical or electrical interruption.



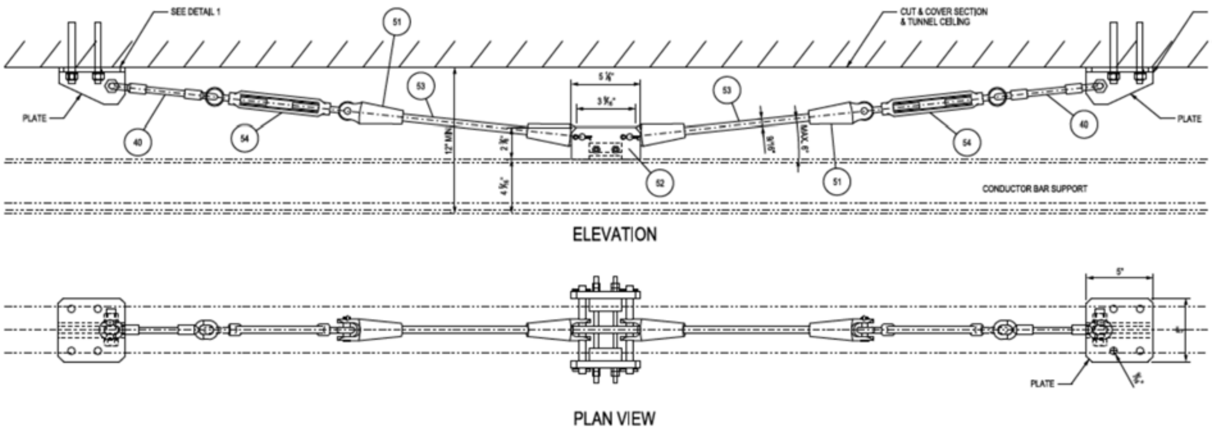
CR-OL-01 & CR-OL-03
TYPICAL CONDUCTOR BAR
UNINSULATED OVERLAP/EXPANSION JOINT

Transition Bar

In most cases, the overhead conductor rail system will eventually need to be integrated with a catenary system. The transition bar is the assembly utilized to make the integration possible while also maintaining the integrity of the catenary and conductor rail systems. The transition bar takes up and absorbs the vibrations from the contact wire of the catenary system and reinforces it with an increasing cross section onto the full profile of the overhead conductor rail. It also is utilized to take the catenary's contact wire's tensile force and transition it to another structural element.

Fixed Point Anchor

The position of long conductor rail systems is determined by fixed point anchors between the expansion elements. These compensate for varying longitudinal forces in the overhead conductor rail caused by any inertia in the hinges of the support structure or the gliding elements. Long conductor rail sections fixed to pendulum support structures do not necessarily need fixed point anchors. The profile section's own weight can provide sufficient stabilization depending on the situation.



CR-MP-01 & CR-MP-02
TYPICAL CONDUCTOR BAR ARRANGEMENT
MIDPOINT ANCHOR
(FOR TYPE CR-MP-02 ARRANGEMENT TO BE WALL SUPPORTED)

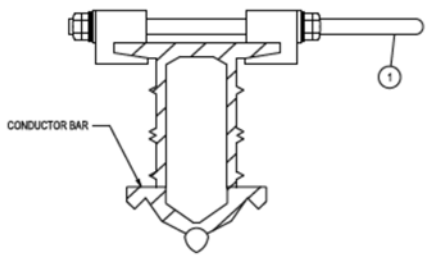
The endpoint anchors take up the tensile forces of the contact wire as it passes into the overhead conductor rail. Once inside the ends of the conductor rail, the contact wire is installed without being subjected to tensile forces.

Turnouts, Crossovers, and Curves

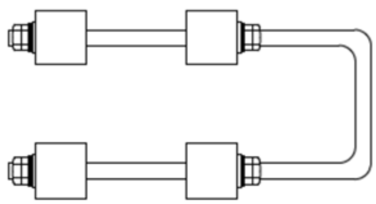
Where tracks branch off, the overhead conductor rail is run parallel to the conductor rail above the main track. In order to ensure the pantograph runs smoothly, the ends of the overhead conductor rails which branch off are bent up with a large radius. The rails themselves can be bent in the field for large radii curves to follow the track or can come pre-bent from the manufacturer for tighter curves.

Grounding

Just like the catenary system, the overhead conductor rail will at times need to be grounded for maintenance purposes. Depending on the project and the design of the support structures, this can be done either on each support structure or by using special current carrying grounding clamps.



ELEVATION



CONDUCTOR BAR EARTHING CLAMP
CR-EC

Sectionalizing

Section insulators are designed either with parallel overlapping conductor rails or with inline section insulators for the conductor rail. For speeds> 87 mph, section insulators with special skids may be utilized. Phase separation is achieved in the same way if it is required.

Section Insulator

Option for providing in-line sectionalizing.

Protective plastic cover

At particularly exposed damp places, the overhead conductor rail is protected against water by a plastic cover. Because of their open shape, the transition bars are usually covered. On ramps, the conductor rail is equipped with a water deflector. The cover is not structural and does not provide electrical insulation, however it does offer some protection to the conductor rail itself.

Advantages

- Rigid catenary system reduces tunnel clearance required, which can offer reduction in tunnel sizing and construction costs.
- Maintenance costs are reduced through time-saving installation and replacement techniques.
- As the tensile stress is eliminated, the rigid catenary system allows more contact wire wear without creating the risk of breaking, which improves the system longevity and tunnel safety. This also decreases maintenance costs as the wire does not need to be replaced as often.
- The system location is generally fixed, and not subject to typical blow-off scenarios that catenary wires experience, which allows for precise positioning and reduces horizontal clearances.
- Electrical sectionalizing overlaps can be created in a short span location vs. catenary overlaps that typically require multiple spans.

- No auto-tensioning equipment is needed to maintain tension through temperature variation.
- No high-tension terminations are required with typical OCS installations.
- Large cross-sectional area of the conductor rail that clamps the contact wire can deliver increased current carrying capability. This could allow for a reduction in required ancillary feeders or even reduction in the number of substations required.
- Allows smooth consistent underrun contact, which provide high quality performance.
- Breaks in the contact wire in the conductor rail system do not result in a cascading effect of additional failures or dewirements down the line that catenary systems typically encounter.
- Wearing surface (contact wire) can be replaced in sections when worn out with tools/devices provided by the manufacturer.
- The conductor rail can have the plastic covering applied to increase the longevity of the system as its shielded from the elements.
- Standard off the shelf hardware material from the manufacturer is typically available.

Disadvantages

- The initial material cost is higher than a conventional catenary system.
- The design is typically non-standard and unique to the application. Some manufacturers withhold detailed information which requires the manufacturer to be part of the design process.
- Requires skilled and trained installation.
- Tight radius curves must be pre-bent and not adjusted in the field as necessary.
- Typically, spans must be supported every 40 feet maximum.
- Buy-America clauses sometimes prevent the use of certain manufacturers which have the most experience and provide high quality installations.

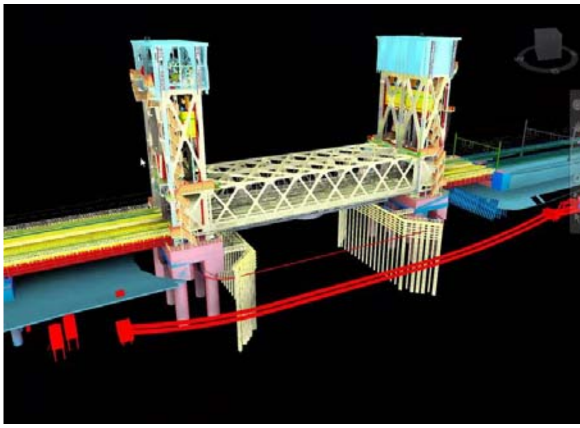
Appendix A – Other OCR Applications

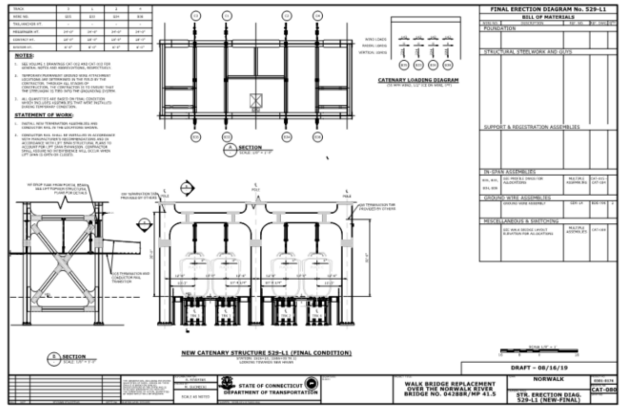
Movable Bridges

Movable bridges are unique structures that require precise coordination of overhead electrification supports. Depending on the style of the bridge, which include rotating swing spans, vertical lift spans, or drawbridge-style bascule spans, the need for an electrical section that allows for that motion is a requirement. A typical catenary system is not a favorable option due to the tensions that it must maintain and the precise integration of the fixed span next to the movable span as the vehicles must operate on the tracks and electrification when the bridge is in its operating condition and either removed, relocated, or allowed to move with the bridge when in its open condition. Conductor rail allows for the overlap or electrically connected section to reside in a relatively isolated location that does not interfere with the other elements of the bridge.

HNTB has experience with the following two movable bridges.

The Thames River Bridge in Groton, CT was replaced on the heavily-operated Northeast Corridor. The existing auto-tensioned catenary was terminated on either side of the bridge and transitioned to conductor rail. The center lift section of the bridge utilized fixed conductor rail to allow for operation while the bridge was closed and raising of the bridge when operation on the tracks ceased.





Another heavily used railroad bridge on the Northeast Corridor is being replaced due to deterioration and operational failures. A system similar to the Thames River Bridge is being proposed for the Norwalk Bridge in Norwalk, CT.

Maintenance Shops

Vehicle maintenance shops offer another key location for the application of conductor rail. Typically the maintenance being performed inside the shops can occur on all locations of the vehicle, including the top where the electrification resides. Conductor rail in this application offers the same benefits mentioned with the tunnels and movable bridges, but it also offers the ability to be movable, such that work can be completed without the physical and electrical encumbrance. Additionally, the use of small "windows" in shop doors can allow for the conductor rail to be installed inside and outside the building without having the concerns that a catenary system would offer.

HNTB has experience with the following two vehicle maintenance buildings.

The existing conductor rail system in the Roberts Yard Maintenance Building and Car Wash Facility in Philadelphia, PA was replaced due to lack of availability of spare parts and the existing system reaching the end of its useful life. The client was interested in utilizing a modern, commercially available, and easy to maintain conductor rail system that provides similar or improved operational characteristics.


At the Southampton Yard Drop Table in Boston, MA, catenary outside the maintenance building was transitioned to a movable conductor rail system inside the building that allows workers to access the tops of the vehicles. A sophisticated Kirk key system was developed for deenergizing the conductor rail and allowing for it to rotate and move against the wall, utilizing motorized and slave support arms.

Retractable Overhead Conductor Rail

Many locations and applications require the removal or relocation of the electrification over the top of a vehicle. Typically, this is seen in maintenance shops, but could also be required for emergency purposes or in government-mandated free space zones, such as above a passage that would allow large vehicles to pass across the electrified territory. In those instances, the use of moveable conductor rail is an option that allows for the conductor rail to be retracted quickly and out of the way. Manufacturers provide the mechanisms and associated safety controls that allow the operation to occur seamlessly. Typically one or multiple, depending on the length, motorized arms

are utilized to rotate the conductor rail in once direction, while slave arms are hinged on a pivot bearing and follow the motorized arm's direction of motion. The support can be horizontally or vertically arranged. When in the non-operating position, controls can be incorporated that not only monitor the conductor rail's position, but can also ensure that the system is grounded and locked into place until certain protocols (human and mechanized) are met before rotating back into position and becoming energized.

END OF MEMORANDUM