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Submarine Cable Installation Techniques and Alternatives

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ABSTRACT

Submarine Cable Installation Techniques and Alternatives

Most movable bridges rely on submarine cables to provide power and control circuit conductors between near side, far side, and pivot piers. Traditional submarine cables utilize armored and water proofed insulation to complete multi-conductor cable assemblies. Recent variations of the traditional types of submarine cables include fiber-optic cables and cables with hollow centers that act as flexible non-metallic raceways. Users can install various conductors and cables into the raceways and can remove and replace conductors over time. The installation and use of submarine cables for movable bridges has become increasingly difficult over the years due to permitting complexities, U.S. Coast Guard and U.S. Army Corp of Engineers requirements for greater burial depths, exposure to deeper draft vessels, and scour conditions. With material and installation costs steadily rising, and manufacturing lead time increasing, many bridge owners and engineers are looking for alternatives.

This paper will explore existing submarine cable materials and installation techniques. Non-traditional materials and methods will also be investigated including directionally bored multi-ducts. Utilidors, micro-tunnels, trenching techniques, and jacking and boring will also be explored. The paper will present movable bridge installations that do not use submarine or under-channel cables including wireless installations. Case history studies will be included with first-hand accounts from owners, engineers, and suppliers.

I. Introduction

The need for submarine cables has been in existence for over 150 years. The purpose of a submarine cable is to carry electrical power circuits, control circuits, and communication circuits from a near shore to a far shore under a body of saltwater; although the use of submarine cables also includes bodies of freshwater. Submarine cables came into existence around the 1850s to support the new telegraph communications technology. Samuel Morris proposed a submarine cable consisting of a single copper conductor to be installed from North America to Europe under the Atlantic Ocean. The present day construction of submarine cables has improved considerably since then; although many of the improvements that make the cable we use today came after World War II. Up until the 1940s, submarine cables consisted of raw rubber from rubber trees, jute, hemp, and copper. Please refer to Figures 1 and 2 for a comparison of submarine cable cross-sections from 1858 and 2008. Present-day submarine cables also include the use fiber-optic communications in addition to power and control circuits that use copper or aluminum conductors.

Figure 1: Submarine Cable Cross-Sections

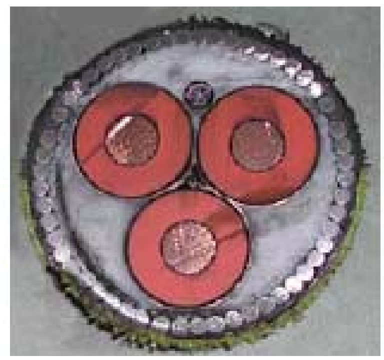
Figure 2: Medium Voltage Armored Submarine Cable

This paper will discuss some of the traditional materials and installation techniques for submarine cable as they apply to the movable bridge industry. Movable bridge types include bascule spans, swing spans, vertical lift spans, and floating draw spans over navigable channels and waterways. As usual in the movable bridge industry, there is no one-size-fits-all solution for all types of bridges, or for all geographies and geometries when it comes to submarine cables. The design and material selections to support movable bridge installations require a substantial degree of customization. Six case studies will be explored for specific movable bridge installations. The names and locations of these bridges have been withheld due to Homeland Security concerns. This paper will also explore alternatives to the traditional submarine cable installations and will include directional boring, aerial cable alternatives, and wireless network communications for controls and interlocks. A simple cost analysis and comparison will be made among the alternative solutions.

II. Purpose and Definitions

A. General

Movable bridges require the use of electrical conductors for power, control, and communications systems. It is necessary to furnish electrical power for electromechanical or hydraulic systems that operate the movable spans. It is also necessary to provide electrical power to operate traffic control devices such as traffic barriers and traffic warning gates. It is also necessary to provide control system circuits, safety interlocks, and communication circuits to both the near side and far side of the movable bridge. The cables are required to complete circuits from the near side to the far side of the movable bridge.

Submarine cables have traditionally consisted of customized cable assemblies constructed of materials designed to withstand the harsh submarine environment. Submarine cables consist of high quality insulation such as cross-linked polyethylene. They often included steel armor on the outside of the conductors which is then also covered with an insulating material to withstand abrasion and aggravating effects of the submarine environment. The materials in these special manufactured cables generally exceed standard building type wire with respects to materials, manufacturing techniques, and associated factory testing.

In some cases it is possible to utilize bridge superstructure to route these conductors. One such example is with vertical lift bridges that have superstructure connections between the vertical lift bridge towers. Conductors for this type of application involve aerial cables specifically designed for the application and require external messenger wire for support. The aerial cables are also specially manufactured cables as with the submarine cables. Their quality generally exceeds standard building type wire with respects to materials, manufacturing techniques, and associated factory testing.

There are alternatives to utilizing copper or fiber-optic conductors for communications and controls. These options consist of wireless communications and control systems. Redundancy is important for both power and control circuitry, and this requirement must also be met when designing wireless systems. Circuit redundancy requires that at least one or two extra copper or fiber-optic cables be installed. With wireless systems, redundancy requires one or two additional pairs of transmitter/receiver sets or modems to get signals across the navigational channel.

The quantity and type of control circuits vary with the control system architecture designed for a particular bridge. In some cases, all safety interlocks and control functions are implemented via hardwired relays. In other cases, programmable logic controllers (PLC) with distributed remote input/output (I/O) modules are used. A substantial number of control circuit conductors can be eliminated when using PLCs. The control circuit conductors are replaced with the multiplexing capabilities of redundant communication networks that connect the PLC I/O modules on the near side and far side of the bridge. An in-depth discussion of control system architecture and configurations for movable bridges is beyond the scope of this paper. However, it is critical to note that the AASHTO (American Association of State Highway and Transportation Officials) movable bridge specifications and the CHBDC (Canadian Highway Bridge Design Code) code <u>require as a minimum</u> that every movable bridge have an emergency stop function consisting of a hardwired circuit capable of removing power from operating equipment. [Refer to AASHTO LRFD Movable Highway Bridge Design Specifications (2007) Section 8.4.2.5 and CHBDC (2006) Section 13.10.21.]

B. Types of Movable Bridges

The requirements for submarine cables are somewhat different for different types of movable bridges. Electrical power, instrumentation and controls, and communication circuits are needed for the electrical equipment on the near and far sides of the bridge. This equipment includes traffic gates, drive motors, pumps, valves, lights, limit switches, control switches, and may include span locks among other required devices. The number and size of the circuit conductors varies widely based on the power consumption requirements the electromechanical equipment, their placement on the structure, and the location of the control room and any electrical equipment rooms.

Bascule bridges may have electrical and machinery rooms located on each bascule pier. Some bascule bridges such as the rolling span Scherzer style bascule have a machinery room that is located on the moving span. For swing spans, it is necessary to provide circuits for the near and far side piers in addition to the center pivot pier. It is usually possible to get from the near side to the far side of a vertical lift span using the bridge's fixed superstructure between the towers, or by providing tower structures to support aerial cables. Aerial cables can be installed for any movable bridge if it is practical to install poles or towers sufficiently high to satisfy vertical clearance requirements of the navigating vessels.

A floating drawbridge has a unique set of requirements among the types of movable bridges. This type of bridge is typically used where the water is deep (over 100 feet), the crossing is wide (over 1 mile), and the approach geography and geometry make it impractical for conventional pier construction. The floating drawbridge consists of a series of hollow concrete or steel pontoons with a single or double draw span that is floated back, or to one side, to open a navigable channel. Connecting circuits between the near and far sides of the floating drawbridges can use any of the cabling techniques discussed. Because of the channel depths and wide crossings, it is most practical to use wireless controls with two electrical service drops, or suspended submarine cable that is designed to be self supporting since it does not reach the channel bottom.

III. Traditional Submarine Cable

A. General

Submarine cable is a collection of individual conductors of various sizes typically consisting of copper or aluminum manufactured to strict specifications of the ICEA (Insulated Cable Engineers Association, Inc.), NEMA (National Electrical Manufacturers Association), and UL (Underwriters Laboratory, Inc.) organizations. Submarine cable insulating materials and fabrication vary among different styles and some weigh much more than others. Many cable assemblies include steel armoring around the circumference of the cable assembly jacket. The steel armor can be galvanized plow steel, stainless steel, or other types of metal. Submarine cables also include fiber-optic conductors for communications and control systems. It is important to note that the manufacturing standards must be strictly complied with in order to obtain a quality product. Additionally, it is important that the completed cable assembly be thoroughly tested at the factory prior to shipment, after it has shipped to the bridge site prior to installation, and again after the submarine cable has been installed.

Original submarine cable materials used in the 1850s consisted of tar, raw tree rubber, jute, hemp, and copper. The construction evolved to include steel reinforcement cables or lead sheathing. The present-day submarine cables are constructed from cross-linked polyethylene insulating materials with non-hygroscopic fillers, HDPE (high density polyethylene) jackets, and various types of steel armor wire or wire rope for stiffening and support (Figures 1 and 2). This includes copper conductors and fiber-optic conductors. The diameter of submarine cables can vary anywhere from 1 or 2 inches in diameter up to 4 or 5 inches in diameter. There are practical limitations to the diameter of the cable that can be easily handled, so design considerations should consider multiple runs of smaller diameter cable in the 2 to 3.5 inch diameter range.

Installation techniques should consider the overall weight of the submarine cable. The cable laid on dry land will be more than the weight of the cable in a body of saltwater or freshwater. For example, a submarine cable of the configuration typically used for many of the smaller Florida bascule bridges has a weight in air of 5 pounds per foot and a weight in salt water of 2.5 pounds per foot. This particular cable assembly consists of fifty No. 12 AWG copper conductors with galvanized steel armor wire and is covered with an HDPE outer jacket with an overall diameter of 2.5 inches.

B. Cable Standards

Submarine cable manufacturing and testing standards include the following:

- NEMA Publication No. WC-70
- NEMA Publication No. WC-57
- ICEA Publication No. S – 95 – 658
- ICEA Publication No. S – 73 – 532

C. Installation Methods

Most submarine cable installations throughout the United States require permitting. Requirements for the cable installation depths under the navigable channel vary substantially among the various authorities having jurisdiction. The submarine cable depth requires consideration for the type of bottom each navigable channel has, and consideration for any future plans to dredge the channel. For example, if the channel bottom is solid impenetrable rock, or coral bed, it is not going to be practical or cost-effective to install submarine cable via trenching or plowing. Details concerning the permit installation depths are beyond the scope of this paper. The submarine cable installation techniques include trenching, plowing, and jetting under the channel bottom with high pressure water (Figure 3). These techniques are usually limited to 6 to 8 feet installation depths below the channel bottom.

Figure 3: Submarine Cable Plow

Submarine cables can be supported using various methods. One popular method that is used with armored cable is to remove the outer insulation down to the armor and splay the armor out in a “wagon wheel” spoke fashion, and clamp the armor strands between heavy wall pipe flanges. This technique has been used successfully for many years. Precautions should be taken to avoid dissimilar metals contact that may result in premature failure due to corrosion. Additional methods for supporting submarine cables include woven mesh type grips also known by brand name as “Kellum” grips, and cable yokes. When using Kellum grips and cable yokes, care should be taken to ensure that the submarine cable assembly has been designed and fabricated to be self supporting.

Figure 4: Concrete Mattress

Figure 5: Concrete Half-Pipe Shell

In some cases, the submarine cable is simply anchored to the movable span pier and laid across the channel bottom. When laid on the channel

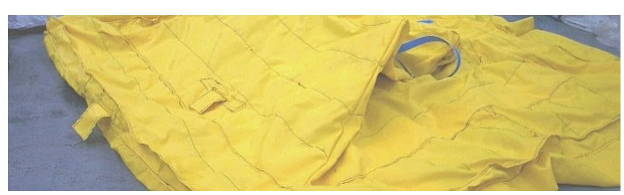

Figure 6: Grout Injected Fabric Form

bottom, the heavy armored cable may be covered or anchored using various methods. Anchoring techniques include concrete blocks with stainless steel hardware, helical anchorage screws similar to those used to moor large vessels, covered with channel bed liners made of fiber and concrete, or covered with concrete mattresses (Figures 4, 5, and 6).

Figure 7: Split Conduit Protection

Existing or new submarine cable can be encased with stainless steel split conduit for added protection. This split conduit is also useful as a point for anchor straps used with helical anchors (Figures 7 and 8). For cable assemblies that are suspended vertically for more than 60 feet, it is prudent to have the cable assembly manufactured with internal steel messenger wire ropes to support the weight of the cable. The National Electric Code, NEC Article 300.19 requires vertically installed conductors to be supported every 60 to 100 feet of vertical rise depending on the conductor size.

Figure 8: Helix Anchor

IV. Alternatives to Submarine Cables

Alternatives to submarine cables include the use of aerial cables supported by messengers, building wire installed in an underground conduit system, and wireless controls. Tables 1 and 3 compare different types of cables considering their cost and approximate service life. When designing for building wire installed in underground conduit, consideration must be given to the type of insulation used for these conductors. Any conduit installed underground will inevitably become full of water, silt, sediment and insects (Figures 9 and 10). The use of standard building wire in this environment will have a shorter service life when compared with that same building wire installed in aboveground dry conduit systems. It does not matter how the underground conduit is installed, whether by directional drilling, jacking and boring, or trenching. Conduit seals installed to prevent water and debris intrusion will eventually deteriorate and leak in a short period.

Figure 9: Underground Conduit

Design considerations must be given to the minimize stress placed on the conductors in order to achieve the best service life. All cables, including submarine cables, fiber-optic cables, and building wire have minimum acceptable bending radii for all installations. There are also minimum bending radii for conduit to which the installation must adhere. Table 2 lists the recommended minimum bending radii for different types of cables and conduit frequently used. It is important to note that NEC Article 353.12 does not permit the use of HDPE conduit inside buildings or exposed to sunlight. Therefore, if using directionally bored HDPE as a substitute for traditional submarine cable, the HDPE conduit cannot enter the electrical rooms or control houses.

Channel crossing methods using tunneling, or caissons for jacking and boring were not explored in depth. These methods are considered to be expensive to permit and construct and require systems dedicated to dewatering. These methods would only be practical if they were incidental to the movable bridge project and were being installed otherwise.


Figure 10: Dry Utilidor

A. Directional Bore

Directional drilling for movable bridges consist of installing a larger outer duct of HDPE material (10 inch diameter is a typical size) through which additional inter-ducts either HDPE or schedule 80 PVC are installed. The outer duct may be flooded with water intentionally to help reduce its buoyancy due to the installation being below the water table. Otherwise, not being flooded, the HDPE outer duct will tend to want to float and rise if soil conditions will permit. The building wire insulation must be rated for wet locations which would be an insulation type identified by the National Electric Code as an RHW, THW, or XHHW-2 among other types. The "W" designation indicates the insulation is acceptable for wet. The "W" type insulation consists of rubber or neoprene that is designed to be watertight and can be installed and submerged in water. THW is a thermoplastic type insulation that is also waterproof. Neither RHW nor THW type insulation will provide good resistance to the chafing and abrasion that they may be exposed to when being installed in underground conduit. XHHW-2 consists of a cross linked polyethylene insulation that is both waterproof and resists abrasion, and is considered a preferred type of insulation by some engineers when using building wire in underground conduit for movable bridges.

It is the author's opinion that the building wire installation service life will be approximately 1/2 or less that of the traditional submarine cable or aerial cable. This opinion is based on 35 years of design and inspection experience with submarine cable installations and building wire installed in underground conduit systems. This is a broad statement and consideration must be given to specific geographies and geometries for each movable bridge. The engineer must consider flow and scour rates of the navigation waterway as well as tides and other influencing factors that may affect longevity of the conduit and cable systems. Directional drilling installations for movable bridges is a fairly recent technology in use, so the industry is lacking specific empirical data with respects to conductor and conduit longevity. It is recommended that a solid mandrel be pulled through the conduit to clear debris and to determine if any areas of the conduit have collapsed during the installation when using directional drilling for the installation of HDPE or PVC conduit.

Directional drilling requires a large radius along the bore path (typical minimum radii are 70 to 100 feet yielding a 15 degree drilling approach). Because of the large radius, the entry and exit locations are very far from the center of the channel, in some cases up to 500 feet (Figure 12). The large distances make it necessary to use oversized conductors to minimize circuit voltage drops. The distances involved with directional drilling also limit the use of this method due to property ownership and land access right of way. It may be possible to obtain temporary access to perform the directional drilling and then, at a location closer to the movable bridge, dig vertical tunnels to intercept the directional bore. This technique will allow electrical vaults to be closer to the movable bridge and can limit conductor lengths and can be a workaround for property access issues. The engineer must survey for underground utilities, and should perform geotechnical sampling to verify there are no underground obstructions or impenetrable materials. Most boring machines have the capability to penetrate almost any material given sufficient time and tool bits. The engineer should also conduct a historical review of the bridge site to be aware of the site's previous uses. Sites previously used for hazardous materials or old bridges may create permitting challenges or have buried obstructions. One such historic bridge site dates back to the 1830s when a canal was constructed. The site use and canal maintenance over the following 180 years has limited the feasibility of directional drilling (Figure 11). The depth of the canal's sheet pile walls (>70feet deep) would require a directional bore to begin more than 450 feet away.

Figure 11: Deep Sheet Pile Wall for Canal

B. Aerial

It is usually possible to get from the near side to the far side of a vertical lift bridge by using the fixed superstructure between the towers. Where there is not fixed superstructure, aerial cable support hangers can be constructed. Using aerial cables for vertical lift bridges requires stainless steel suspension (messenger) wires and saddles to support the cable for the length between the bridge towers. Vertical lift bridges tend to have longer spans than other types of movable bridges and it is not uncommon for the tower to tower distances to be greater than 300 feet.

Vertical lift bridges present an additional challenge to bring electrical power, controls and communications from the fixed structure to the movable span. If the vertical lift bridge is a tower drive configuration, then most of the electromechanical equipment is on the fixed portion of the bridge and it is relatively easy to access with electrical cables. For tower driven vertical lift bridges, only a small amount of electrical power and controls are required to be distributed on the lift span. These circuits are usually for navigation lights, aerial beacons, skew control instrumentation, and general lighting and receptacle services. For vertical lift spans that are span driven configurations, it is necessary for a substantial amount of power and control cable to be routed to the span. This is especially true when the electrical and control rooms are also mounted on the movable span. For span driven vertical lift bridge applications, it is recommended that insulated power rails and specialty flexible aerial (droop) cable be used as engineered specifically for this service. As with submarine cable, the aerial cable is designed and fabricated to stringent criteria to withstand the harsh environment including ice, wind, and UV radiation. Otherwise, aerial cable installations on movable bridges will not achieve a reasonably good service life expected to be up to 50 years.

C. Wireless Communications and Controls

Wireless technology offers an alternative to copper conductors and fiber-optic cables for control interlocks and communications. This alternative includes the use of wireless communications from the near side to the far side of the movable bridge. There are a large number of reliability and security issues associated with the use of wireless communications and control systems. These considerations are beyond the scope of this paper; however, industrial standards that govern the safe use of wireless control systems include the following:

- International Society for Automation, ISA-99 Industrial Automation and Control Systems Security.
- International Organization for Standardization, EN ISO 13849 – Machine Control Safety.
- International Electro-Technical Commission (IEC) 62443 Network and System Security for Industrial Process Measurement and Control.
- IEC 61508 and IEC 62061 Machine and Drive Control Safety Standards.

It is important to note that the EN ISO 13849 standard for machine control safety replaces the now obsolete EN 954 standard. One interesting point associated with the standards for wireless communications and controls is the definition of fail-safe communication. A “Category 3” safety level prohibits a single fault from defeating a safety interlock. The design standards include “open channel” communications that require a constant transmitting and receiving protocol between two transceivers to ensure the control signal is not interrupted. For movable bridge application, the requirement of this standard may not be practical since a large vessel passing through a movable bridge may temporarily interfere with the communication signals between the antennas on the near and far side piers.

As mentioned above, the AASHTO design specifications for movable bridges and the CHBDC require that emergency stop functions for movable bridges be accomplished with hardwired circuits that remove power from the controlling devices. It is recommended that bridge operations be conducted with personnel on both the near and far side of the structure where bridge control systems utilize wireless controls where it is not possible for emergency stop circuits to be hardwired.

Wireless communication networks for controls and interlocks can replace the need for cabling between the near and far side of movable bridges. It is still necessary to obtain electrical power to both the near side and far side of the movable bridges where electromechanical or hydraulic operating systems are used. It is necessary to obtain independent electrical service entrances for each near side and far side when providing this type of installation. Each bridge “facility” includes both the near and far sides. When providing a single bridge “facility” with more than one electrical service entrance, it may require permission from the authority having jurisdiction. A single “facility” is generally restricted to one electrical service entrance by the NEC Article 225.30. Having two electrical services typically require installing placards at each service entrance disconnect location identifying that the facility is served by two service entrances with the location of the disconnect switches identified on the placards. Care must also be taken by the engineer to coordinate with electric power utilities to verify that each of two separate electrical service entrance ground systems can be bonded together. In some cases, the power generation source for one side of the bridge is different than for the other side of the bridge and there is a possibility for the grounds to be at different potentials. Movable bridge inspections have documented measurements of as much as 100 volts difference between a near side ground and the far side ground because they originated from different power grids. In many cases, the bridge steel itself bonds the near side and far side grounding systems together regardless of what the electrical engineering restricts.

Wireless communications systems can be extended to include phone line modems, and internet protocol (IP) interfaces. In 1983, a telephone modem was installed on a movable bridge with the baud rate of 9.6-kBd. It was successfully used as an emergency backup for control and communications from the near side to the far side of this movable bridge. This dedicated phone line modem operated with two solid copper type “bell” wires that connected to the telephone service. This modem interfaced with a PLC with local I/O modules with the remainder of the control system being hardwired relays. This configuration operated successfully for 25 years until it was replaced in 2008. With wireless control systems, the designer needs to determine whether to use a dedicated frequency for communications between the transceivers or to utilize spread spectrum frequencies. It is recommended that a wireless survey be conducted of the area to identify the amount and complexity of wireless users in the vicinity of the movable bridge prior to making this decision. The wireless services now with newly adopted Federal Communications Commission (FCC) regulations allow dedicated frequency bands for emergency services such as fire and rescue. It may be possible for owners of movable bridges to obtain FCC permission to use these frequency bands.

V. Field Testing

All conductors and cable used on movable bridges must be field tested to determine their suitability for service. This testing is in addition to the manufacturers’ quality assurance and quality control testing performed at the factory which is required to comply with the cable standards and specification criteria. The preferred testing method for low voltage conductors (600V or less) is the insulation resistance test commonly referred to as Megger Testing. Megger testing for new installations should be performed in compliance with the NETA ATS (International Electrical Testing Association- Acceptance Testing Specifications). The requirement for 600 volt rated insulation is to test it at 1000 volts d.c. for 1 minute. The minimum acceptable measurement value is 100 mega ohms. Medium voltage cable (submarine, aerial, or other types) that are rated greater than 600 volts requires additional testing to determine its suitability for service. The two most popular testing methods for medium voltage cable are partial discharge and high potential testing. The latter method commonly called “Hi-Pot” testing can be a destructive test when performed on substandard cable and this method is being replaced with the partial discharge method.

It is necessary to test each conductor to ground, and all conductors to the other conductors in a cable assembly or in a common conduit when performing megger tests. The conductor to ground test should be performed with an identify ground point reference. It is recommended that armored cable use the armor as a ground reference after the armor is electrically bonded to the bridge grounding system.

Table 1: Cable Installation Pros & Cons

Material & Installation	Pros	Cons
Submarine Cable:		
a. Trenching & Plowing	-Longevity high, 50 yrs+	-Expensive Material
	-Secure & Safe	-Limited depth 6 to 8 ft.
	-Allows hardwired interlocks	-Environmental Issues
b. Laying on Bottom w/Cover	-Economical Installation	-Expensive Material
	-Good Longevity	-Reduced Service Life
	-Allows hardwired interlocks	
c. Laying on Bottom w/Anchors	-Economical Installation	-Expensive Material
	-Good Longevity	-Reduced Service Life
	-Allows hardwired interlocks	
d. Laying on Bottom Only	-Very Economical Installation	-Expensive Material
	-Medium Longevity	-Unstable
	-Allows hardwired interlocks	-Reduced Service Life
Directional Bore:		
a. Unarmored Submarine Cable	-Longevity, 50 yrs +	-Expensive
	-Can replace conductors	-Long Cable Runs
	- Environmentally Positive	-ROW Issues
	-Deep Installations	-Voltage Drop
	-Secure & Safe	-HDPE Prohibited from Buildings
	-Allows hardwired interlocks	-HDPE Prone to Collapse
b. Building Wire	-Standard Materials	-Reduced Service Life
	-Can replace conductors	-Long Cable Runs
	- Environmentally Positive	-ROW Issues
	-Deep Installations	-Voltage Drop
	-Low Tech	-HDPE Prohibited from Buildings
	-Secure & Safe	-HDPE Prone to Collapse
	-Allows hardwired interlocks	
Jack & Bore	-Can replace conductors	-Expensive unless incidental with another project.
	-Low Tech	-Difficult to access
	-Secure & Safe	-Caisson, deep trench, coffer dam required.
	-Allows hardwired interlocks	
Aerial	-Longevity, 50 yrs+	-Expensive
	-Can replace conductors	-Difficult to access
	-Secure & Safe	-Limits Vertical Clearance
	-Allows hardwired interlocks	-Requires Superstructure
Wireless:		
a. Transmitter/Receiver	-Economical	-Medium security risk
	-Requires PLC or equivalent	-Medium safety risk
		-Obsolescence prone
		-Requires PLC or equivalent
		-Not AASHTO Compliant
		-Not CHBDC Compliant
		-Not NEC Compliant
b. Phone Modem	-Economical	-Medium safety risk.
	-Low security risk	-Requires PLC or equivalent
	-Requires PLC or equivalent	-Not AASHTO Compliant
		-Not CHBDC Compliant
		-Not NEC Compliant
c. Internet Protocol	-Economical	-High security risk
	-Flexible Configuration	-High safety risk
	-Requires PLC or equivalent	-Obsolescence prone
		-Requires PLC or equivalent
		-Not AASHTO Compliant
		-Not CHBDC Compliant
		-Not NEC Compliant

Table 2: Minimum Radii for Cable & Conduit Bends

Cable Type	Minimum Bending Radii- Multiple of Overall Diameter	Comments
Traditional Submarine Cable (stranded):		
Control & Instrumentation	4 (inner edge)	Manufacturer Recommendation
Unshielded Power	4 (inner edge)	Manufacturer Recommendation
Shielded Power	8 (inner edge)	Manufacturer Recommendation
Fiber-optic	12 (inner edge)	Manufacturer Recommendation
Building Cable (stranded):		
Unshielded Conductor (600V)	4 to 8 (inner edge)	Manufacturer Recommendation
Shielded Conductor (600V)	12 (inner edge)	Manufacturer Recommendation
Multi-Conductor Shielded Assembly (600V)	12 x individual shielded conductor dia. (inner edge)	Manufacturer Recommendation
USE, SE, UF (600V)	5 (inner edge)	NEC Article 338.24
Unshielded Conductor (>600V)	8 (inner edge)	NEC Article 300.34
Shielded Conductor (>600V)	12 (inner edge)	NEC Article 300.34
Multi-Conductor Shielded Assembly (>600V)	7 x overall dia. or 12 x individual shielded conductor dia. (inner edge)	NEC Article 300.34

Conduit Type	Minimum Bending Radii- Multiple of Nominal Diameter	Comments
PVC (Sch. 40 & 80) 2 inch	4.75 to 6 (centerline)	NEC Article 352.24
PVC (Sch. 40 & 80) 4 inch	4 to 6 (centerline)	NEC Article 352.24
PVC (Sch. 40 & 80) 6 inch	5 to 6 (centerline)	NEC Article 352.24
*HDPE (SDR 13.5) 2 inch	13 (centerline)	NEC Article 353.24
*HDPE (SDR 13.5) 4 inch	15 (centerline)	NEC Article 353.24
*HDPE (SDR 13.5) 6 inch	**	*Note: HDPE is not permitted in buildings. **See Manufacturer.

VI. Case Studies

Example 1: New Bascule Bridge (Submarine Cable- Power & Control)

Four leaf bascule bridge; 100 foot wide navigable channel; 40 foot navigational clearance when leaves are down; 30 foot deep navigation channel; single electrical service (480V, 3-phase).

Traditional submarine cable installed for power, controls and communication using multiple runs of four cable assemblies – two for power and two for controls and communications. Control system utilizes programmable logic controllers with remote I/O. Certain safety interlocks remained hardwired, and used hardwired relays for manual maintenance control options some far side equipment. Navigation channel current was relatively swift at 3 to 4 knots or more. Submarine cable was installed in the sandy bottom 6 feet deep using water jets. However, due to the current and tide characteristics of this channel and the propensity for scour, it is uncertain how long the submarine cable will remain buried. The collective weight of the cables is expected to keep them on or near the channel bottom.

Example 2: Rehabilitated Bascule Bridge (Directional Bore- Power & Control)

Two leaf bascule bridge; 150 foot wide navigable channel; 55 foot navigational clearance when leaves are down; 40 foot deep navigation channel; single electrical service (480V, 3-phase), (Figure 12).

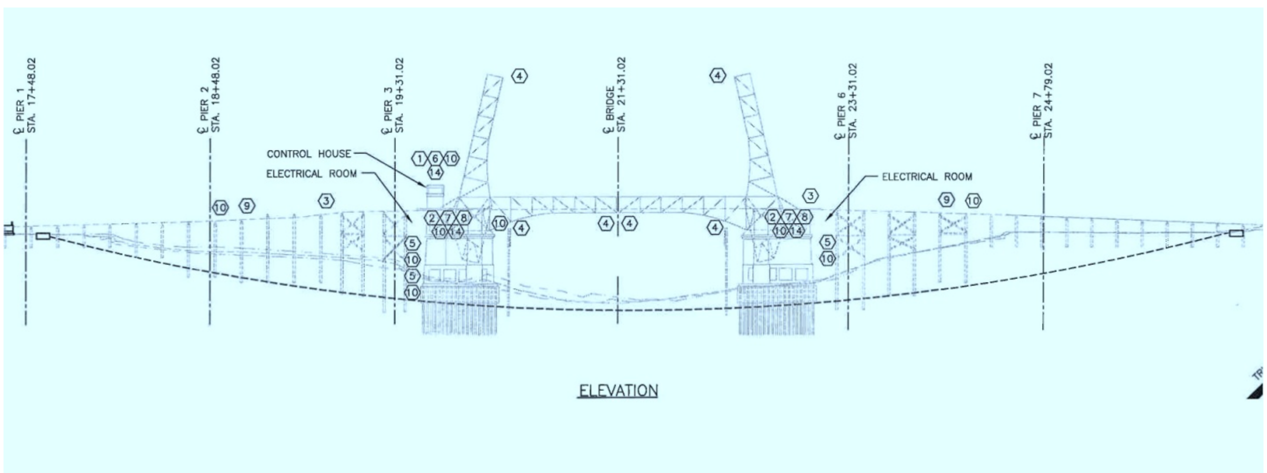

Figure 12: Example 2 –Directional Bore

This bridge utilized directional drilling installing a 10 inch diameter HDPE outer duct and four 2 inch PVC inter-ducts with power and control conductors. These conductors had type XHHW-2 insulation and were general building wire. Electrical vaults were used on the near and far sides of the bridge where directional bore conduit terminated. The conductors were brought up to terminal boxes above ground and the conductors were then routed back towards the center of the channel to the bascule piers. This bridge design utilized PLC control with remote I/O modules and included redundant networks for I/O module communications. The navigation channel was 40 feet deep and was scheduled for additional dredging up to 50 feet deep within the next 10 to 15 years. Because of this future dredging, the directional bore needed to be 30 feet below the bottom of the navigable channel. To accomplish this, the directional drilling started on the near side approximately 500 feet away from the center of the channel. The bore used a 700 foot radius and came up on the other side of the channel on the far shore approximately 500 feet to the far side of the channel centerline. Total distances involved from the near side vault to the far side vault for the directional drilling was approximately 1,100 feet and 70 feet deep. The actual bore depth varied +/- 10 feet from the bore's centerline over the bore's length. Therefore, the total cable distance from the near side bascule pier to the far side bascule peer was approximately 1,800 feet in order to traverse a 150 foot wide navigable channel.

Example 3: New Bascule Bridge (Dry Utilidor Tunnel- Control)

Two leaf bascule bridge; 120 foot wide navigable channel; 40 foot navigational clearance when leaves are down; 40 foot deep navigation channel.

The bridge has two separate electrical services, 480V, and 3-phase- one for each side. Therefore, only control and communications cables need to cross the channel. The utilidor was intended to be a dry tunnel large enough for maintenance personnel to walk through to access utility piping and electrical conduits mounted to one side. This utilidor now remains completely flooded at all times except when it is pumped out for inspections. The bridge communication and control network cables are routed through the utilidor and consist of building wire in PVC conduit. This installation was completed approximately 25 years ago and there have been no reported cable failures during that period. The inside of the utilidor is coated with a fine silt and sediment that feels like oily clay. The waterway is brackish and most hardware in the utilidor that was not stainless steel has corroded away, (Figures 10 and 13).

Figure 13: Bascule Bridge w/Utilidor

Example 4: Floating Concrete Drawbridge (Submarine Cable- Control)

Two floating draw spans; 150 foot wide navigable channel; over 80 foot deep navigation channel restricted to approximately 40 feet by suspended submarine cable, (Figures 14 and 15).

Figure 14: Floating Drawbridge Profile

The bridge has two separate electrical services, 15kV, 3-phase- one for each side. Therefore, only control and communications cables need to cross the channel. This bridge utilizes traditional armored submarine cable for controls and communications. The bridge spans a lake with depths of 200 feet. The bridge has two floating draw spans that open to create the navigable channel. The submarine control cables are self-supporting and are suspended and drooped from the near side stationary portion of the floating bridge to the far side stationary portion of the bridge. The radius of the submarine cable is sufficient to provide a navigable channel depth of approximately 40 feet before it would create an interference. Power distribution for this bridge originates independently through electrical service entrances on the near side and far side. Each electrical service is 15 kVA class medium voltage distributed towards the center of the bridge to the electrical rooms. Power is transformed to 480 V, 3-phase. The control system for this bridge uses a PLC with remote I/O modules and redundant communication networks. The original submarine cable for this bridge was installed approximately 50 years ago and was replaced twice during that period of time- once as part of a rehabilitation, and once due to a bridge accident.

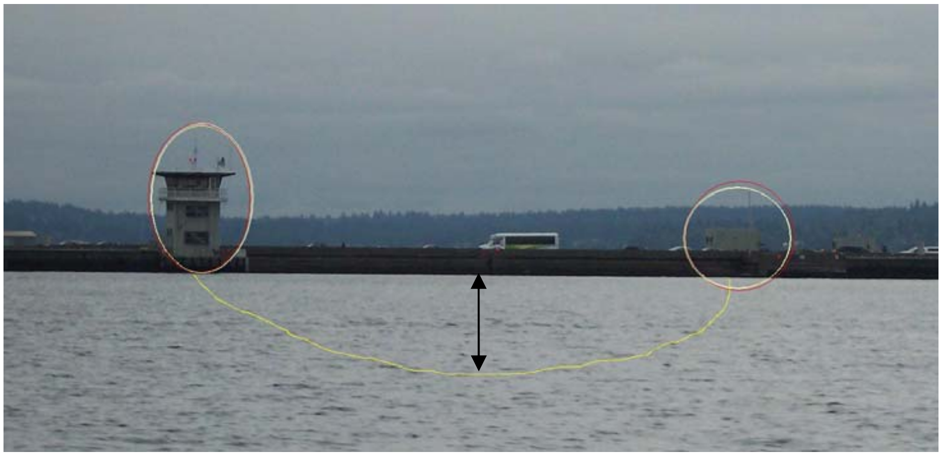

Figure 15: Floating Drawbridge Elevation (cable depth >45 feet)

Example 5: Floating Concrete Drawbridge (Wireless Control)

Two floating draw spans; 600 foot wide navigable channel; over 80 foot deep navigation channel, (Figures 16 and 17).

The bridge has no hardwired submarine cables. The bridge has two separate electrical services - one for each side. Electrical services are 15 kV Class, 3-phase medium voltage for distribution to the bridge electrical rooms. The medium voltage is transformed to 480 V, 3-phase power. Control and communications is accomplished using redundant wireless modem communications and PLCs with remote I/O modules. The bridge has two floating draw spans that retract to create a 600 foot wide navigational channel. The channel depth is approximately 100 feet deep. The wireless communication modems are connected to redundant communication networks, redundant power supplies, and redundant transmitter receivers. The wireless modems utilize spread spectrum frequency hopping. The location of the bridge is sufficiently remote from urbanized areas such that a dedicated frequency of operation to avoid wireless interference was not necessary.

Figure 16: Floating Drawbridge (arrow marks center draw span in Figure 17 with wireless control)

Figure 17: Floating Drawbridge w/Wireless Controls (600 feet channel opening)

VII. Cost Comparison

A cursory cost comparison was performed for the bridge in Example 2 above. Table 3 provides cost comparison data for the actual directional bore installation compared with the hypothetical costs if submarine cable or aerial cable were used. The least costly option was the submarine cable at $275,000, followed by the directional bore cost of $311,000, and the aerial cable cost of $319,000. It is once again important to understand the objectives and limitations when evaluating installation costs for movable bridges. In this example, while the cost for the submarine cable was the lowest, it did not meet the project requirements for installation depth. The submarine cable could only be installed 6 feet under the channel bottom and the project needed the cable to be 30 feet deep to accommodate future dredging.

The directional bore installation required using 500 feet of approach right of way that was available and did not need to be purchased. Purchasing the right of way could easily tilt the cost against this installation method. The long distance needed for the bore required larger power conductors than the other methods to minimize the circuit voltage drop. Even with his addition cable size cost, the bore method remained competitive. Selecting the bore diameter is critical in controlling the cost of this method. The drilling costs go up exponentially as the bore diameter increases beyond a 10 inch diameter.

There are limitations associated with the aerial cable installation that also need to be considered. The vertical clearance for the bridge is limited to 60 feet when using aerial cable. This clearance limitation may be acceptable depending on the permitting agency requirements and the types of vessels using the channel. A major portion for the aerial cable cost is in the supporting masts. This cost would be reduced if there were existing masts or superstructure at the site, and if the vertical clearance could be reduced.

Table 3: Cost Comparisons for a Bascule Bridge (Reference Example 2 Above)

CABLE & MATERIAL TYPE/SIZE	**RETAIL MATERIAL COST**	**INSTALLATION LABOR COST**	**QUANTITY**	**TOTAL COST** thousands	**SERVICE**
Directional Bore:				$311.2	30 ft. deep 25 yrs+
Boring 10 inch dia.	n/a	$20/ft.	1,100 feet	$22	
CU Building Wire: 5-#3/0 XHHW	$25/ft.	$16/ft.	1,900 feet	$77.9	
CU Building Wire: 20-#10AWG XHHW-2	$6/ft.	$10/ft.	1,900 feet	$30.4	
CU Building Wire: 60-#10 AWG XHHW-2	$18/ft.	$30/ft.	1,900 feet	$91.2	
10” HDPE Duct (SDR-11)	$10/ft.	$7/ft.	1,100 feet	$18.7	
Three 2” Sch. 80 PVC Inner-ducts	$15/ft.	$21/ft.	1,900 feet	$68.4	
Electrical Vault	$500	$800	2	$2.6	
Submarine Cable:				$274.8	6 ft. deep 50 yrs +
Plowing/Jetting	n/a	$32/ft.	150 feet	$4.8	
25 CU conductor cable (5-#1/0, 20-#10AWG XLP)	$200/ft.	$50/ft.	500 feet	$125	Smaller wire due to short run/lower voltage drop
60 copper conductor cable (60-#10 AWG XLP)	$240/ft.	$50/ft.	500 feet	$145	
Aerial Cable:				$318.9	60 ft. vertical clearance limited. 50 yrs+
High Mast Pole 80ft.	$50k ea.	$50k ea.	2	$200	
5-#1/0 stranded EPR cable w/SS messenger & saddles	$40/ft.	$25/ft.	580 feet	$37.7	Smaller wire due to short run/lower voltage drop
30-#10 AWG EPR cable w/SS messenger & saddles	$45/ft.	$25/ft.	580 feet	$40.6	
30-#10 AWG EPR cable w/SS messenger & saddles	$45/ft.	$25/ft.	580 feet	$40.6	

CONCLUSION

There is no one-size-fits-all solution for movable bridges when it comes to submarine cable applications. Some techniques and solutions are less expensive than others. The engineer must assess the risks and benefits associated with each technique for a specific movable bridge installation. The least expensive solution may not be the best solution. High levels of reliability are required and long-term service is desirable. Table 1 provides some pros and cons associated with various methods. Table 2 provides a summary of cable bending radii for installation reference and evaluation. Table 3 provides a cursory cost comparison for three methods. There are cost benefits to providing engineered systems and high quality products. Benefits include minimizing maintenance inspections, testing and repairs for installed cable, and avoiding unexpected bridge operational failures. Wireless communication and control systems allow for economical installations, but there are safety and security issues associated with the configuration. Wireless systems require a higher degree of skilled maintenance when compared with other with hardwired control systems. Wireless system options tend to evolve quickly with electronics market with electronics technology advancements and equipment and spare parts quickly become obsolete and difficult to obtain.

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