Utilities in Multi-Purpose or Shared Structures

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ABSTRACT

With population growth, expansion of industrial demands, and the challenges of installing high voltage (HV) and extra high voltage (EHV) cables in dense urban and other locations, structures such as tunnels and bridges for multi-purpose use are becoming attractive options. They offer the potential for reduced overall costs, environmental advantages, and less disruption to the community during the installation, maintenance, and replacement of cables and other utilities. The International Council on Large Systems (CIGRE) released a Technical Brochure 403 in 2010 through Working Group B1.08 titled "Cable Systems in Multi-Purpose or Shared Structures." This brochure was developed to (1) establish the appropriate terminology; (2) collect global data on the experience with the use of multi-purpose and shared structures for the installation of cable systems; (3) provide a survey of technical aspects, such as types of cables, design of the structure, installation, mutual impacts among the utilities, maintenance, and operational constraints; (4) provide economic, occupational health and safety aspects, administrative matters, legal aspects, and decision-making process; (5) summarize and review the information to identify the issues that need to be considered when installing insulated cables systems in multi-purpose or shared structures; and (6) recommend guidelines for the use of cables in such structures.

INTRODUCTION

This paper reviews the Technical Brochure as it applies to utility engineering, whether it be electrical utility, communications utility, gas utility, or water/wastewater utility, to promote more widespread use of such structures in future utility infrastructure projects. Encouraging legislation has fueled the use of shared or multiple-use structures in the last two decades in major cities in Australia, China, France, Japan, Korea, Netherlands, New Zealand, Singapore, Spain, and Sweden, but because of a challenging legal atmosphere that prevails in the United States and Canada, widespread data collection on existing projects that rely on sharing or multiple use structures was not feasible. However, some examples from shared structures in the United States will be presented at the annual conference in 2025. The structure of the Cigré report summarized in this paper is that the reader can review Sections 1 to 5 and the examples described in Section 8 to decide if a shared structure is appropriate. If it is appropriate, Sections 6 and 7, which deal with the different technical and administrative issues, provide guidance in designing and implementing such a system. Future trends are summarized in Section 9.

A Shared Structure is defined as a single or multi-purpose structure jointly used, owned, or managed by one or more entities. In Japan, the term Common Tunnel is also used to describe a tunnel shared by voluntarily participating utilities. Typical projects from Spain, Sweden, and the Netherlands are shown in Figures 1, 2, and 3.

Figure 1: Power cables and communication cables in a Madrid Tunnel

Figure 2: Typical Multi-purpose Tunnel in Stockholm

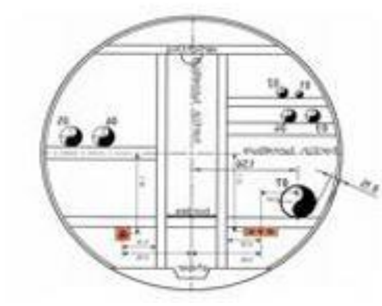

Figure 3: Cables, water, sewage and gas through shared tunnels in Netherland

TECHNICAL ISSUES

When considering power cables installed in a multi-purpose structure with other services, some technical issues that should be regarded are electromagnetic compatibility between the power cables and sharing systems, fire behavior of cable systems and other systems, possible fault occurrences, and external effects of the fault maximum length of cable link without the use of shunt reactive compensation, effects of cables on the structure and its performance, as well as effects of environmental conditions on the wires.

The cable arrangements, minimum clearance distances to other services, and access are methods to decrease the effects of electromotive force (EMF). Where the calculated EMF exceeds prescribed values, mitigation arrangements must be implemented in the structure, (Cigré, 1996). The electromagnetic interferences must be carefully assessed, mainly if the cables and the circuits are likely to be affected by induction and are very close. The problem of electromagnetic interference must also be considered for direct current (DC) cables. A static magnetic field generated by a direct current cannot induce voltages or currents on electrical circuits. DC converters, however, generate harmonic voltages and currents on the DC and AC sides. The problems of electromagnetic interference from DC transmission can be reduced by using cables with a metallic sheath that is thick enough and solidly bonded. This will allow the induced currents to circulate in the sheath and provide a good screening effect. Even if this sheath has a high resistivity, such as lead, it has a discrete screening effect at harmonic frequencies. AdaMagnetic interference from DC transmission can be reduced by using cables with a metallic sheath that is thick enough and solidly bonded. The rating of cables installed in tunnels or similar enclosed structures can be calculated using IEC documents for simple situations. Still, complex cases require more calculations, such as using the finite element analysis shown in Figure 4 for the magnetic field, (Doris, 2009).

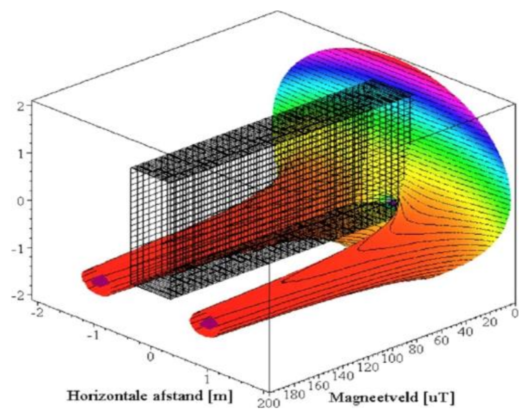

Figure 4: The magnetic field in the tunnel at maximum cable loading.

Size Requirements and Constraints

The inside diameter of a tunnel and the space required on a bridge should be carefully evaluated. For instances where two tunnels intersect, the design for the placement of services on the walls and floors of the tunnels must be closely studied, and the civil engineering design of the intersection should ensure that the minimum bending radii of all existing and future services entering the side tunnel are not compromised. Furthermore, it is necessary to consider the static and dynamic forces associated with the utility services.

Monitoring Systems

Video cameras located at strategic points can monitor access to the structure as well as monitor security and personnel safety. Monitoring of air quality, humidity, temperature, fire, and water levels in enclosed structures, should also be considered. Monitoring systems for gas pipes are essential to detect any hazardous gas leaks.

Communications (telephone stations or two-way radios)

To improve safety for the public at large in structures shared with transport and utility personnel, it is recommended that a reliable fixed or portable communication system be able to be provided. In the case of a fixed system, telephones would be installed and identified at regular intervals to reduce the distance required to reach them. If portable systems are favored, some fixed antennas might be necessary to ensure the reliability of the communication system. Leaky co-axial cable or directional antennas for straight structures may be used.

Fireproofing Measures for Cables

To protect the cable and retard a fire's progress through the structure, physical protection of the wires can be used. The cable also be manufactured with a fire-retardant jacket, or a fireproofing material may be applied once the cable has been installed. Cables can also be installed in fireproof troughing or buried in the case of tunnels. Fireproofing cables and other potentially flammable services in tunnels are considered essential. Ventilation and cooling systems, using water or refrigeration, may be installed in the tunnel to increase the rating of the cable system.

Transportation Systems

Depending upon the length of the structure, a means of transportation for the installation and maintenance of services and for evacuating personnel may be required for some tunnels. The choice depends on the length, gradients, and accessibility of the tunnel.

Vermin Barriers

Protection against vermin migration and the population of the tunnels is necessary. The use of poison at the entrances of the tunnel is a common practice. Such removable vertical barriers at the tunnel entrance are commonly used to prevent vermin intrusion and do not restrict access when required.

Emergency Power Supplies

To ensure the safety of personnel and the installation in case of loss of the leading electric power supply, it may be advisable to install an emergency generator that would automatically come online. The generator capacity should be sufficient to ensure essential lighting and ventilation services.

Bridges

Bridges are more visible than tunnels; usually, there is greater public exposure to installed services. Some services installed on bridges are in enclosed spaces and should be given similar consideration to tunnels. To ensure security, personnel, and material safety, some essential services must be considered in designing, constructing, or modifying bridges as multi-purpose structures. Existing bridges built strictly for vehicles may not be suitable for installing utilities due to physical or loading constraints. However, designers of new bridges should be encouraged to consider integrating other services. Figure 5 is from a bridge designed to accommodate several waterlines and conduits for electrical and communications utilities and providing for additional utilities in the future.

Mechanical Protection

Cables and other services installed on a bridge may be subjected to vandalism and animal attacks. Mechanical protection should be provided to protect installed equipment. The automatic protection of the cables on a bridge should be designed such that no part of the bridge can be easily dismantled, and techniques that enhance the security of mechanical protection should be employed.

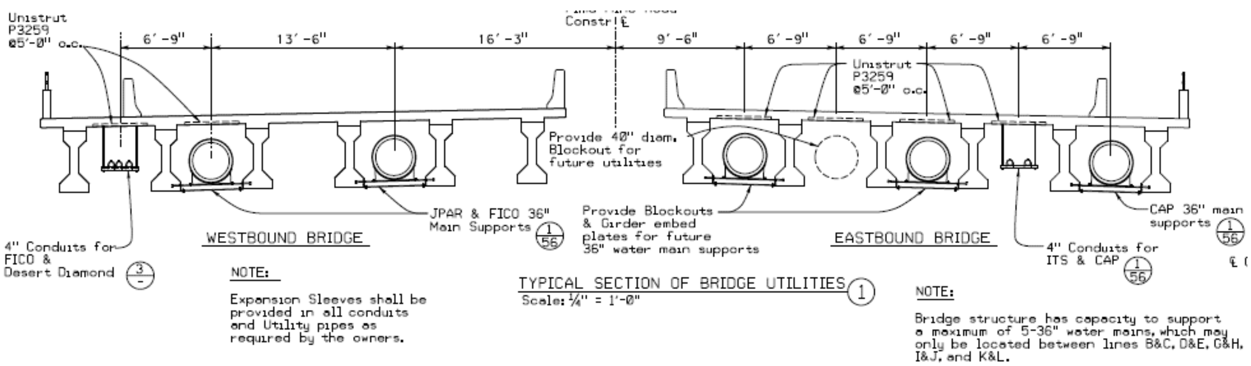

Figure 5: Bridge design to carry multiple utilities

Exposure to Weather

Where the cables are exposed to weather, consideration must be given to how weather will impact the cable system and the safety and work of personnel. Weather protection may be required to be designed into the structure. Exposure to solar radiation can affect the rating of cables and could deteriorate a cable's outer protective covering. Solar shielding devices or coverings can protect cables from the sun.

Cables

To minimize the project's costs, cables over one kilometer in length have been installed in tunnels and bridges. Special reels and arrangements could be necessary to allow for the pulling of such a long length. In tunnels, cables could be installed in free air or enclosed in troughs that prevent the possibility of fire propagation resulting from a significant failure. The clamping arrangement and the distance between the clamps should be studied. For cables on bridges, it is essential to check the thermo-mechanical behavior of cable systems under different load conditions and their expansion and contraction relative to the bridge structure. Expansion loops may be necessary to accommodate these differences. Figure 6 shows the compactness of cabling on multiple supports while allowing for ease of personnel and equipment movement for maintenance.

Figure 6. Cable tunnel for multiple utilities

Effect on the Structure and its Performance

The weight of the cables, accessories, and supports attaching them to a bridge and their effect on its performance must be carefully analyzed. Installing a long high-voltage cable circuit on an existing bridge would add a substantial static load and exert some dynamic forces on the structure. Specialists could undertake detailed studies of their integration when determining necessary modifications to ensure safety. It is imperative also to consider the vibrations of the bridge structure caused by vehicular or train traffic that would be transferred to the cables and accessories. Unique vibration-damping arrangements may be needed to prevent premature failure of the cable system. Also, if high-pressure pipeline valves are closed or opened, there can be a considerable pressure wave, leading to the movement of the pipes when they are not fixed in the structure.

Drainage of Seepage

Ground water seeps into most tunnels and will accumulate in the tunnel if not drained. The seepage amount depends on the soil's nature, the type of tunnel construction, seasonal variations of the groundwater table, hydraulic gradients, and the tunnel depth relative to local water tables. Accumulated water could cause damage to equipment, produce a foul smell in the tunnel, and contaminate the tunnel's atmosphere. Draining the accumulated untreated water can take time and expense, requiring water testing and permits for disposal. If the tunnel is to be readily accessible, it should be regularly monitored and drained.

NON-TECHNICAL ISSUES

Security and Safety

Rules, procedures, and permits should be agreed upon, known, and applied by each structure user. Workers should be trained and have procedures to assess and control the risks of working safely around each other's services in that environment. A clear identification of each user's services should be provided.

Public and Height Safety

When a cable is visible or accessible to the public, a physical barrier and precise electrical hazard identification shall be provided. Workers must wear and use equipment or other means adapted for working at heights by local regulations. All safety aspects concerning personnel and equipment should be addressed in multi-purpose structures' feasibility and design phases. The following is an attempt to cover the most essential aspects and is not exhaustive.

Access, Vandalism, and Surveillance

Access to tunnels and reserved spaces on bridges should be limited to authorized personnel. Many commercial technologies are available to control access, such as unique key systems with restricted copying rules, magnetic cards, closed circuit TV systems, and electrically controlled access doors. A record of all penetrations by utility crews should be kept. It should include the names of people entering the restricted areas, time of entrance and exit, a brief description of the work to be done, an inventory of equipment and vehicles (if any), and any other information the utility considers pertinent.

Communications

An efficient and reliable communications system should be installed and used during the construction phase. A permanent communications system should also be envisaged to enhance the safety and security of operation and maintenance personnel. Fiber optic communication cables are preferred to regular copper wires as they are not influenced by magnetic fields that could induce undesirable noise. Phones should be installed regularly to facilitate communications for utility and other crews.

Rules and Regulations

National and local as well as an organization's rules and regulations on safety and other relevant issues need to be rigorously followed. All evacuation routes, distance to exits, and essential emergency telephone numbers should be well-posted at regular intervals in tunnels or on bridges. Local authorities should be made aware of the details of all installed equipment. This would facilitate the work of emergency personnel such as police, firefighters, and paramedics, who would be called upon to aid during rescue operations. Emergency plans should be prepared and approved by the utility management. The utility crews and local emergency personnel should practice regular training exercises to ensure the highest level of safety and security.

Obstacles to Sharing a Structure and Investment Risk

According to the working group survey results, utilities are reluctant to share structures if there are other ways of achieving the desired objective, even if they incur a higher cost. The main issues are safety, security, technical and legal. The importance of the installation and its compatibility with the other services could hinder the negotiation process. Considering the significant capital investment and operating costs involved, it is essential to undertake an investment risk analysis. Usual risk analysis techniques can be used. To ensure the viability of sharing a structure, it is essential to consider any future services that may be installed and the actual project.

Feasibility Stage Considerations

It has been assumed that other options have been dismissed before committing to a partnership agreement for sharing a structure. These options would include single-purpose structures, open-cut construction, Horizontal Directional Drilling (HDD), submarine cables, overhead construction, the availability of existing access ways, Gas Insulated Lines (GIL), superconductivity, and distributed generation. Sometimes, what utilities are going to use the proposed structure is not precisely known. Then, engineering the structure can be a difficult task that turns future usage possibilities on or off.

Cleaning and General Maintenance

Multi-purpose structures should be kept as clean as possible. A maintenance program should be established to ensure that debris does not accumulate and that all the essential services of the structure are working correctly, hazardous materials are not stored in the structure, and access /exit ways are Services in the Tunnel to ensure personnel and material safety and security, some essential services must be considered in the design and construction of a tunnel. They include:

Lighting and Ventilation

It is a common practice to provide lighting at the tunnel access areas only where activity in a tunnel structure is irregular. Where a tunnel is regularly entered, however, it is recommended that some form of lighting system be provided to ensure that workers can carry out their activities safely without needing extra equipment. DC lighting systems could be an economical alternative because they can use a battery source in emergencies. An adequate ventilation system should provide a suitable atmosphere and evacuate undesirable gases and contaminants. Ventilation systems may also be necessary in deep tunnels to ensure a reasonable ambient temperature for workers. Ventilation systems should be designed to mitigate any fires within the structure. There is a balance between mitigating fires within the structure and containing smoke density. Ventilation systems assist with cable cooling.

Emergency Exits and Procedures

Emergency exits should be provided at each end to evacuate the personnel safely and quickly in an emergency. Depending on the tunnel length, intermediate emergency exits should be given consideration. These exits should be unobstructed and adequately identified. Regular and casual personnel should be familiar with the evacuation procedures. Annual evacuation training would help verify the evacuation procedures more so in multi-purpose or shared tunnels than in single-purpose tunnels. The higher usage of the tunnel for working on the different services could also justify the installation and maintenance costs of the communication system.

Fireproofing Measures, Fire and Smoke Detection

Fireproofing cables and other potentially flammable services in tunnels are considered essential. It should be noted that some cable designs are unsuitable for use in tunnels unless the tunnel is equipped with fire protection services such as sprinklers/sprays or if the cable has some additional form of protection. Installing compatible fire extinguishers in the tunnel for use in a local emergency is also advisable. Longitudinal segmentation along the tunnel with fire doors between segments can also be considered. Tunnels can be crowded and usually enclosed underground spaces with difficult access. A fire can result in a rapid build–up of heat and intense smoke generation in the enclosed space. The smoke produced by combustible materials used in cables and other electrical equipment can be toxic. This makes firefighting in tunnels with wires and other flammable products difficult and dangerous.

Pipe Leak Detection

To minimize damage from chemical discharges and prevent the engulfment of personnel from hazardous atmospheres, appropriate leak detection systems should be included with any pipelines carrying potentially hazardous chemicals or other substances.

Protection of Personnel and Accessibility

Depending on working conditions, rescue equipment, emergency breathing apparatus for confined spaces, and essential personal protective equipment must be provided. Workers must be trained to use this equipment. Material, equipment, and personnel transportation through a long tunnel or on a long-span bridge represents a technical challenge that requires planning to ensure it is done safely. Two vertical shafts may be necessary to install the tunneling machinery and allow excavated materials to be evacuated during construction.

Environment Constraints

During installation, maintenance, and repair work, it is possible to use or generate some substances that can harm people and the environment. It is essential to know the properties of all materials and substances being used and their impact on personnel and the environment. The Material Safety Data Sheets (MSDS) of materials used must be referred to and the recommended controls put in place. Measures should also be taken to protect the personnel and the environment by reducing or eliminating such substances. The use of unique clothes and masks, the installation of local ventilation and filters, and trays under the accessories are measured.

AGREEMENTS ON SHARING OF CAPITAL AND MAINTENANCE COSTS

Because tunnels and bridges require significant capital investment, careful planning is paramount. In the case of shared structures, it is imperative that the involved parties prepare some feasibility studies and negotiate and conclude a detailed agreement before embarking on the project. It is not unusual that such preparation and negotiation would take more than a decade. In Japan, concluding a long-term agreement covering seventy-five years is mandatory. This complexity will depend upon prospective partners' willingness, local rules, cultural aspects, and the regulatory environment. A user should consider the impact of energized cables on other services and people and the ease of installation, maintenance, and replacement. Those interested in sharing a structure should ensure no impediments to sharing with others, such as local regulations, capital investment, running costs, financial arrangements, and insurance. To ensure a sound investment decision, a risk analysis for the cable system and other services sharing the structure should be evaluated for the installation, normal operation, and failure of one or more utility services. Evaluation of the cable system should consider the following criteria: thermal, electrical, mechanical, and ambient conditions.

Case History 1 – ElecLink Project in France and the United Kingdom

Over the past decades, those living in Spain, Japan, China, Australia, New Zealand, Sweden, Netherlands, France, Singapore, and South Korea have ample track record of civil and electrical engineers working side by side to install several utilities in a multiuse structure. The ElecLink project is the crown jewel among the projects sharing tunnels, as shown in Fig 7.

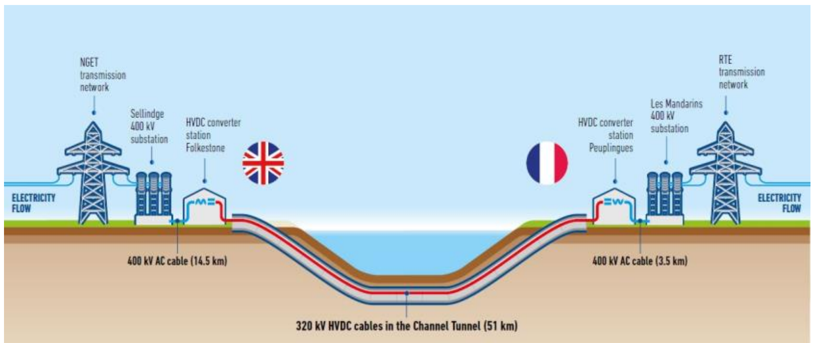

Figure 7: Cross-sectional view of the ElecLink

The concept of a direct current electricity interconnector in the Channel Tunnel was born in 1986 in the fixed link Concession agreement. Eurotunnel Group started to develop this Eleclink concept in 2011. In 2013, the project was granted Project of Common Interests (PCI) status by the European Commission, confirming its entry into a select list of energy projects which are considered essential for completing the European internal energy market and for achieving the European Union's policy objectives of affordable, secure and sustainable energy. In 2014, the project was further endorsed by the national energy regulators, Ofgem in Great Britain (GB) and CRE in France, through their joint Exemption Decision, which the European Commission also approved. Consumers do not underwrite the first privately funded investment in cross-border transmission infrastructure—the first non-subsea link between continental Europe and GB with zero impact on the marine environment. Once operational, the ElecLink interconnector has offered 1000MW of state-of-the-art bi-directional transmission capacity at a time when the security of supply in both countries is expected to be at risk due to aging plants reaching the end of their lifetimes and environmental legislation dictating the phaseout of polluting coal-fired power stations.

Construction works commenced in late 2016. ElecLink has partnered with globally renowned EPC contractors with unparalleled expertise in delivering projects in similar sectors, namely Siemens, Balfour Beatty, and Prysmian. The civil and electromechanical works outside the tunnel were done on time, while the required enabling works inside the tunnel had already been carried out successfully. This paved the way for the project's final stage: installing the DC cables in the north-running tunnel. The cables laid to carry AC are shown in Fig. 8. The total cost was $ 700 million for 63 km.

Figure 8. AC Cables on the UK side

Throughout the project's development, from the initial feasibility studies to date, Eurotunnel has remained committed to satisfying the requirements of the IGC and ensuring that the installation of the interconnector does not impact the current level of safety within the tunnel environment. The project has applied a rigorous and systematic approach to risk assessment in line with the European Railway Safety Directive and European Common Safety Method for Risk Evaluation and Assessment (CSM) Regulations, as well as adopting best industry practices to inform decisions regarding the choice of technology, the detailed engineering design, the location and technical specifications of the apparatus inside the tunnel, as well as the installation methodology. Typical equipment deployed to install the monorail is in Fig. 9.

Figure 9. Installation Equipment in the Tunnel

The project continues to be - subject to independent review by subject specialists. Eurotunnel has also sought many second opinions to provide additional independent verification that all hazards have been identified, properly assessed, and sufficiently controlled before the commencement of the cable hauling activities. In compliance with the CSM regulations, Eurotunnel has appointed an AsBo to provide confidence that introducing the interconnector within the tunnel environment will not adversely affect the current safety level of existing railway infrastructure. Following an extensive review of the project's technical documentation over 18 months, as well as numerous risk assessment workshops, which have included HAZID, HAZOP, and PFMEA workshops, the AsBo concluded that "the project entity will be able to commence installation without detriment to the current level of safety of the fixed link transport system.

FUTURE TRENDS

Sharing tunnels and bridges for multiple utilities is already standard practice in Japan and South Korea. A tunnel, being a structure, also offers a higher level of physical protection compared with burying cables. For bridges, it is an opportunity for cable installation cost savings, particularly as construction and operation costs increase. Projects completed in Madrid, Barcelona, Tokyo, China, Australia, New Zealand, Sweden, Netherlands, France, Singapore, and South Korea over the past decades provide an ample track record of civil and electrical engineers working side by side to benefit humanity. We may build shared or multi-purpose structures to last up to one hundred years, but the organizations that manage and maintain those structures can change. Therefore, we must have systems in place to protect the ongoing use of and access to these structures and the assets they protect. Civil engineers have learned to cope with loads from ice and wind in designing cable bridges, while electrical engineers still put the cables underground at an enormous cost. It would be in the public interest for civil and electrical engineers to pool their knowledge. The problem of providing adequate electricity to recharge battery-powered vehicles in urban environments compels more engineers to embrace the idea of sharing structures for multiple utilities. An inventory of existing potential multi-use structures and a streamlined procedure are needed to take advantage of suitable candidates. There will be lots of federal money available to accelerate this transition**.**

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